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16. Abstract

This report describes a computer simulation developed as a planning tool to aid in establishing future icebreaker requirements for the Great Lakes-St. Lawrence Seaway as a function of projected cargo tonnage, trade routes, winter severity, vessel ice-transiting capabilities, vessel operating restrictions, and alternate icebreaking plans and operating concepts (direct assistance, convoying, and channel ice clearing). The simulation allows the user to determine benefits in terms of reduced commercial transit time, reduced shipping cost and increased fleet tonnage capacity; to assess the impact of user charges on shipping costs; and to investigate alternate fleet mixes of icebreakers and icebreaking tugs and their assigned areas of operation. The simulation has the following two operating modes: (1) a fixed fleet of icebreakers; and (2) maximum response time where the required icebreaker fleet is determined internally.

In addition to describing the simulation, ~~this report al~~so presents validation of the simulation based on U.S. Coast Guard records for the 1975-76 winter navigation season, and the results, conclusions, and recommendations of ten (10) production runs performed to examine the effect on icebreaker requirements of: (1) 20% increase in cargo over the year 2000 projections; (2) convoys; (3) winter severity; (4) imposed vessel restrictions; (5) channel ice clearing; and (6) prohibiting icebreaking tugs from convoying. Based on these runs, a preliminary icebreaker fleet for the Great Lakes was generated to handle the projected cargo in the year 2000.

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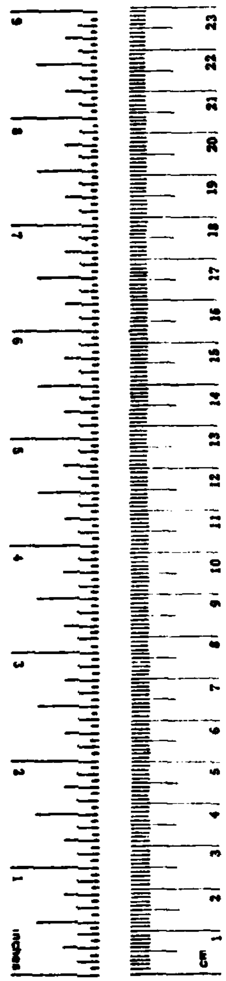
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

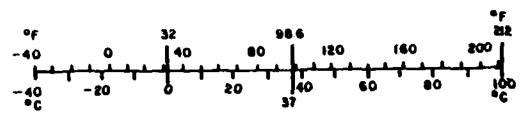
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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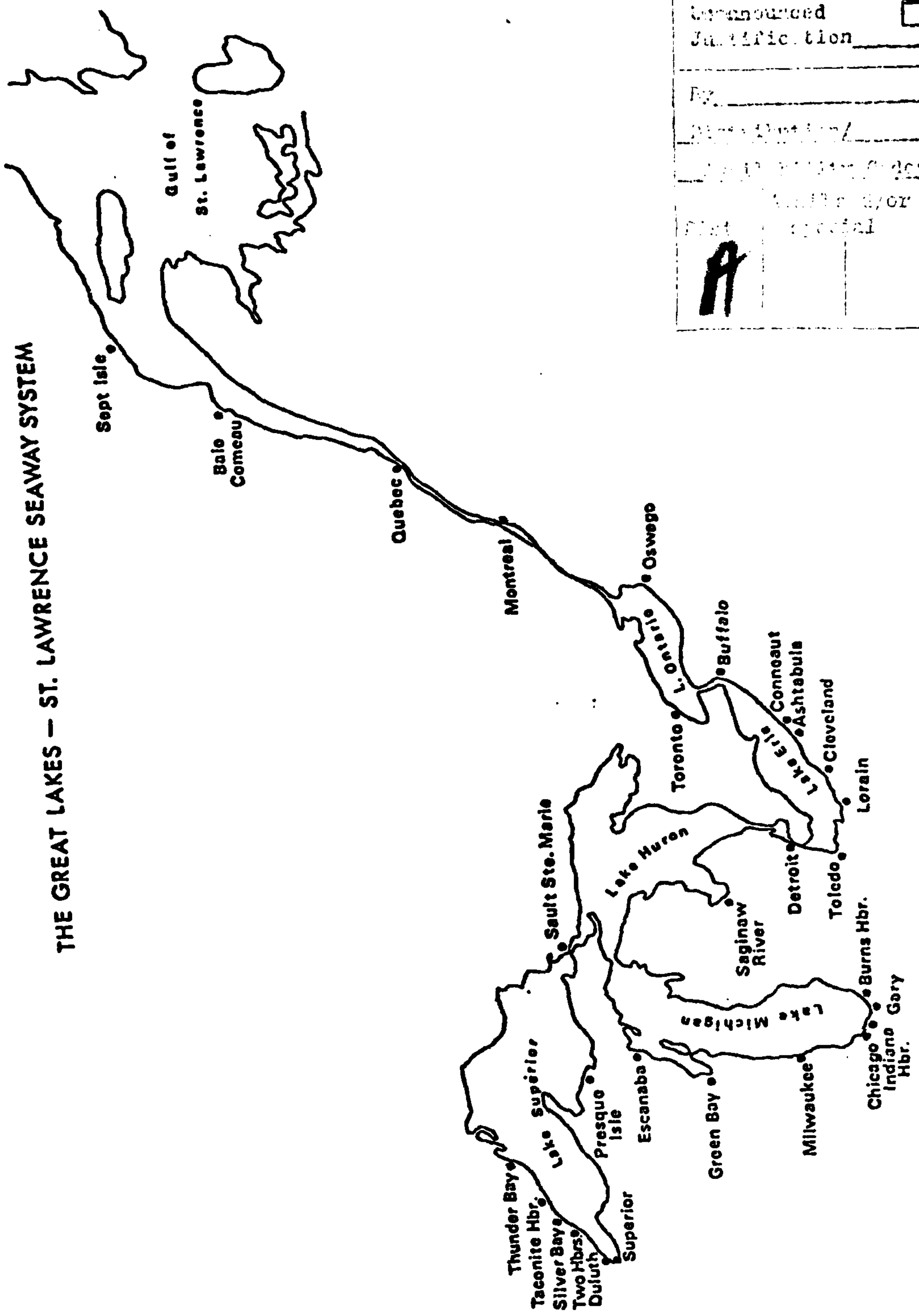

THE GREAT LAKES — ST. LAWRENCE SEAWAY SYSTEM

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1. SUMMARY OF GREAT LAKES-ST. LAWRENCE SEAWAY ICEBREAKER REQUIREMENTS STUDY

OBJECTIVES

The overall objective of this study was to develop a planning tool for use by the U.S. Coast Guard to aid in establishing their future icebreaking requirements for the Great Lakes-St. Lawrence Seaway (GL-SLS) Navigation System as a function of projected cargo tonnage, trade routes, winter severity, vessel ice transiting capabilities, vessel operating restrictions, and alternate icebreaking plans and concepts of operation (direct assistance, convoys, channel maintenance, and channel ice clearing). More specifically, the objectives were to modify the existing GREAT LAKES-ST. LAWRENCE SEAWAY NAVIGATION SIMULATION so that it could be used as a tool to aid in:

- Determining Coast Guard icebreaker requirements for the Great Lakes-St. Lawrence Seaway.
- Determining benefits in terms of reduced commercial vessel transit time and shipping cost and increased fleet tonnage capacity derived from the presence of icebreakers.
- Determining the impact of user charges to help defray costs of icebreaking assistance and channel maintenance during extended navigation season operations.*
- Determining the impact of establishing minimum ship operating requirements, such as SHP/length for ships operating during the extended season.
- Investigating proposed alternate icebreaking plans and concepts of operation (direct assistance, convoys, channel maintenance, and channel ice clearing).
- Examining different fleet mixes of icebreakers and icebreaking tugs and their assigned areas.
- Determining the impact of short term variations in ice conditions on icebreaking effectiveness and requirements.

METHOD OF APPROACH

The GREAT LAKES-ST. LAWRENCE SEAWAY NAVIGATION SIMULATION was developed by ARCTEC for the North Central Division of the U.S. Army Corps

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* Capability included but not examined in this study.

of Engineers and subsequently expanded for the St. Lawrence Seaway Development Corporation to model the movement of ships and cargo within the Great Lakes-St. Lawrence Seaway Navigation System and to and from world areas, during both normal and winter navigation seasons. In simulating the movement of ships and cargo, the model incorporates the following interactions between ships and the system, as well as the interactions between the ships themselves:

- Port and lock limitations and constraints
- Draft limitations
- Speed limits
- Daylight only navigation
- Queues forming, expanding, and diminishing at lock and port facilities
- Increased transit, lockage, and port times due to the presence of ice during extended season operations
- Ships getting stuck in ice and having to wait for icebreaker assistance
- Ships having to convoy and wait for icebreaker escort.

To accomplish the stated objectives, the following modifications were made to the existing simulation:

- Revised ice conditions data in the simulation to better reflect normal and severe winter conditions for light, moderate, and heavy commercial navigation.

- Developed and incorporated a complete set of icebreaker operating subroutines capable of modeling the following modes of icebreaking operations: preventive icebreaking, convoying, and direct assistance for vessels stuck in ice.

- Modified the simulation to include the capability for icebreaker user charges in vessel operating costs.

- Modified the simulation to generate icebreaker statistics, such as number of vessels assisted, total time assisting vessels, response time, and operating hours, to be used to assess icebreaker efficiency and cost of operations.

- Revised icebreaker characteristics in the simulation to better reflect existing, planned, and proposed icebreakers.

- Revised the program to permit two study options: in the first, a fixed fleet of icebreakers is defined; in the second, a maximum response time (variable with area of operation) is defined and the icebreaking fleet determined accordingly.

- Provided data files which can be modified to assess the effect of short term variations in ice conditions on the ability of the icebreaker fleet to maintain commercial navigation.

- Modified the computer simulation as needed to clearly identify all savings in commercial vessel transit times attributable to icebreaker operations when comparing simulation runs with and without icebreaker support.

Once the modifications were incorporated, the simulation was validated using U.S. Coast Guard icebreaking records for the 1975-1976 winter navigation season. Upon completion of the simulation validation, a series of ten (10) production runs, listed in Table 1.1, were performed and analyzed to assess the following:

- Effect of a 20% increase in cargo tonnage with a fixed fleet of icebreakers (normal winter).

- Effect of a 12-hour variation in maximum response time on icebreaker requirements (normal winter).

- Effect of convoys on icebreaker requirements (normal winter).

- Comparison of the maximum response time (MRT) generated icebreaker fleet to the USCG estimated fleet (normal winter).

- Effect of winter severity (normal vs severe) on icebreaker requirements.

- Effect of having only Class B icebreakers escort convoys, as opposed to both Class B and Class C icebreakers, on icebreaker requirements (severe winter).

- Effect of prohibiting vessels with low SHP from operating in the extended season on icebreaker requirements (severe winter).

- Effect of conducting channel clearing in certain channels on icebreaker requirements (severe winter).

- Comparison of the maximum response time (MRT) generated icebreaker fleet to the USCG estimated fleet (severe winter).

TABLE 1.1

PRODUCTION RUNS FOR SIMULATION OF GL-SLS ICEBREAKER REQUIREMENTS

RUN NO.	WINTER TYPE	MINIMUM LAKER CLASS	RUN MODE[1]	USCG ESTIMATED FLEET	MRT (hr)	CONVOYING IB TYPES[2]	CHANNEL CLEARING[2] (in/2wks)	CARGO TONNAGE (year)
1	Normal	5	FIBF	Normal[5]	---	C,B	---	2000
2	Normal	5	MRT	---	Min[3]	C,B	---	2000
3	Normal	5	MRT	---	Min+12	C,B	---	2000
4	Normal	5	FIBF	Normal[5]	---	C,B	---	2000+20%
6	Normal	5	MRT	---	Min+12	No Convoys	---	2000
5	Severe	5	MRT	---	Min+12	B	---	2000
7	Severe	5	MRT	---	Min+12	C,B	---	2000
8	Severe	6	MRT	---	Min+12	C,B	---	2000[4]
9	Severe	6	MRT	---	Min+12	C,B	12	2000[4]
10	Severe	6	FIBF	Severe[5]	---	C,B	---	2000[4]

NOTES:

[1] FIBF = Fixed icebreaker fleet; MRT = Maximum response time.
[2] Convoys and channel clearing in: St. Marys River/Whitefish Bay, Straits of Mackinac, Detroit/St. Clair Rivers, Welland Canal, St. Lawrence Seaway.
[3] Minimum time is that required to get to furthest point in reach from closest home port at 5 mph.
[4] Cargo tonnage on restricted ships assumed carried in normal season.
[5] USCG estimated icebreaker fleet listed in Table 6.10b.

COMPARISONS:

1,4 -Effect of increased cargo tonnage (20%)(normal winter).
2,3 -Effect of variation in maximum response time (normal winter).
3,1 -Difference between MRT generated icebreaker fleet and fixed icebreaker fleet (normal winter)
3,6 -Effect of convoys (normal winter).
3,7 -Effect of winter severity.
5,7 -Effect of not allowing Class C icebreakers to convoy (severe winter).
7,8 -Effect of vessel class restriction (severe winter).
8,9 -Effect of channel clearing (severe winter).
8,10-Difference between MRT generated icebreaker fleet and fixed icebreaker fleet (severe winter).

A summary of the results of the production runs, along with a discussion of the above items, are presented in Section 6 of this report. Based on those results and discussions, the following conclusions and recommendations were drawn:

CONCLUSIONS

1. Usefulness of the Simulation - Based on the validation presented in Section 6.2 and the experience and knowledge we have gained from working with the model, from conversations with ship operators, port officials, and personnel at Coast Guard, MarAd, Corps of Engineers, and the St. Lawrence Seaway Development Corporation, we believe the simulation, as developed, realistically models the Great Lakes-St. Lawrence Seaway System. As a result, it can be used as a valuable tool to aid in the planning process of the Coast Guard in establishing their future icebreaking requirements and alternate icebreaking plans and concepts of operation.

2. Normal and Severe Winter Icebreaker Fleets* - Using the results of the simulation for the fixed icebreaker fleet runs and the generated icebreaker fleet runs, simulation estimated icebreaker fleets were prepared and are presented in Tables 1.2 and 1.3 along wtih the Coast Guard estimated fleets for normal and severe winters. In finalizing the simulation fleet, consideration was given to additional icebreaking demands, such as preventive icebreaking and channel maintenance. In comparing the results of the simulation to those of the Coast Guard, it is interesting to note how closely they compared in number with some shifting in location. *It is important to note that the size and location of the fleet is completely dependent upon the magnitude of the projected tonnage during the extended navigation season and the projected trade routes. A change in either the magnitude of tonnage or trade route can alter the icebreaker requirements significantly.*

3. Formation of New Task Command for Duluth/Superior - Icebreakers in the simulation for the fixed fleet mode continually traveled across Lake Superior to provide assistance in both Duluth/Superior and at the Soo since assistance was provided on a first come-first serve basis. As a result, a large amount of time was spent transiting Lake Superior compared to time spent either assisting or convoying. For example, in Run 1 for the normal winter, the fixed fleet of 7 Class C and 3 Class B icebreakers operated at 100% utilization performing 781 direct assists and escorting 629 convoys. Of the 100% utilization in periods 5, 6, and 7, only 10%,

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* Rationale for simulation generated fleet presented in Section 7

TABLE 1.2

COMPARISON OF SIMULATION GENERATED
ICEBREAKER FLEET WITH COAST GUARD ESTIMATED FLEET
FOR NORMAL WINTER

Task Command & Home Port	U.S. COAST GUARD ESTIMATED ICEBREAKER FLEET – Icebreaker Class				SIMULATION GENERATED ICEBREAKER FLEET – Icebreaker Class			
	B	C	D	TOTAL	B	C	D	TOTAL
Taconite Command								
Duluth/Superior	-	2	-	2	2	-	-	2
Presque Isle	-	-	-	-	-	-	-	-
Sault Ste. Marie	2	4	-	6	1	5	-	6
St. Ignace	1	1	-	2	-	2	-	2
TOTAL	3	7	-	10	3	7	-	10
Oil Can Command								
Escanaba	-	1	-	1	-	2	-	2
Green Bay	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-
Chicago	-	1	-	1	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-
TOTAL	-	2	-	2	-	2	-	2
Coal Shovel Command								
Saginaw	-	-	-	-	-	-	-	-
Port Huron/Detroit/ Toledo	1	2	-	3	-	5	-	5
Sandusky	-	1	-	1	-	-	-	-
Buffalo	1	2	-	3	1	2	-	3
TOTAL	2	5	-	7	1	7	-	8
Seaway Command								
Oswego	-	3	-	3	-	-	-	-
Alexandria Bay	-	-	-	-	-	4	-	4
TOTAL	-	3	-	3	-	4	-	4
TOTAL	5	17	-	22	4	20	-	24

TABLE 1.3

COMPARISON OF SIMULATION GENERATED
ICEBREAKER FLEET WITH COAST GUARD ESTIMATED FLEET
FOR SEVERE WINTER

Task Command & Home Port	U.S. COAST GUARD ESTIMATED ICEBREAKER FLEET — Icebreaker Class				SIMULATION GENERATED ICEBREAKER FLEET — Icebreaker Class			
	B	C	D	TOTAL	B	C	D	TOTAL
Taconite Command								
Duluth/Superior	1	2	-	3	2	2	-	4
Presque Isle	-	-	-	-	-	-	-	-
Sault Ste. Marie	3	6	-	9	2	6	-	8
St. Ignace	2	2	2	6	1	3	-	4
TOTAL	6	10	2	18	5	11	-	16
Oil Can Command								
Escanaba	-	1	-	1	1	-	1	2
Green Bay	-	-	-	-	-	1	-	1
Milwaukee	-	-	-	-	-	-	-	-
Chicago	1	2	-	3	-	1	-	1
Grand Haven	-	-	-	-	-	-	-	-
TOTAL	1	3	-	4	1	2	1	4
Coal Shovel Command								
Saginaw	2	3	-	5	-	-	-	-
Port Huron/Detroit/ Toledo	1	4	-	5	1	5	2	8
Sandusky	1	2	-	3	-	2	-	2
Buffalo	1	4	-	5	3	5	-	8
TOTAL	5	13	-	18	4	12	2	18
Seaway Command								
Oswego	-	3	-	3	-	-	-	-
Alexandria Bay	-	-	-	-	1	3	-	4
TOTAL	-	3	-	3	1	3	-	4
TOTAL	12	29	2	43	11	28	3	42

20%, and 29% of the total direct assist miles and 20%, 58% and 44% of the total convoy miles were spent in actual assistance and convoying for each period, respectively. In comparison, the somewhat larger MRT generated fleet, which was restricted to operating within assigned areas near the icebreaker's home port, averaged 61%, 74%, and 75% of total direct assistance miles and 74%, 70%, and 66% of total convoy miles performing actual direct assistance and convoying in periods 5, 6, and 7, respectively. Future runs should have a 200 mile limitation placed on an icebreaker's area of operation to prohibit crossing Lake Superior, thereby effectively making Duluth/Superior a separate task command.

4. Effect of Increased Tonnage - For the fixed normal winter icebreaker fleet, the designated icebreakers in Oil Can and Coal Shovel could handle the 20% increased tonnage above the projected year 2000 tonnage with no significant problems. For the Seaway, the 3 Class C icebreakers operated at 100% utilization in periods 5 through 8 escorting 173 convoys between Alexandria Bay and Cornwall. Based on the MRT runs 2 and 3, 5 or 6 Class C icebreakers or 1 Class B plus 3 Class C icebreakers are probably required to escort all vessels in convoys at a reasonable icebreaker utilization rate. In Taconite, the fixed fleet operated at 100% utilization because a large portion of the time was spent by icebreakers transiting between Duluth/Superior and the Soo. Based on the MRT runs 2 and 3, in which icebreakers are restricted to operating within assigned areas near the icebreaker's home port, the specified fixed fleet of 7 Class C and 3 Class B icebreakers needs to be increased to 9 Class C and 4 Class B icebreakers with Duluth/Superior being treated as a separate task command.

5. Effect of Increased Maximum Response Time - For Taconite, Oil Can and Coal Shovel Task Commands, there appeared to be only a slight effect on the generated icebreaker fleet due to increasing the MRT by 12 hours. For the Seaway, the maximum number of required Class C icebreakers dropped from 6 to 5.

6. Effect of Convoying - For Oil Can and Coal Shovel, where there were no convoys, the effect of convoying was a change in the arrival of ships from other commands which altered the generated icebreaker fleet slightly. For the Seaway, the elimination of convoying reduced the icebreaker requirements significantly since salties, which were capable of proceeding on their own, were being forced to convoy, thereby requiring more icebreakers. In Taconite, elimination of convoying caused the generated icebreaker fleet to double in periods 5 through 10.

7. Effect of Winter Severity - As one would expect, the icebreaking requirements increased with increasing winter severity. In Taconite, the total number of direct assists increased from 792 to 1032 and the total number of convoys increased from 699 to 937, resulting in an increase of required icebreakers from an average of 11 to 20, with an increase in Class B icebreakers from an average of 4 to approximately 6. In Oil Can, the total number of direct assists increased from 86 to 102, but because the location of the problem reach was closer to the icebreaker home port of Escanaba, fewer icebreakers were required during the severe year. The reason for this seemingly contradictory trend is a result of the use of actual historical weather and ice data which is sometimes inconsistent. In Coal Shovel, the number of direct assists increased by almost 200% from 198 to 573 with 347 convoys being escorted during the severe winter. This resulted in the number of icebreakers being doubled with an average of 4 Class B icebreakers being required during the severe winter while none were required during the normal winter. For the Seaway, the total number of direct assists increased from zero in the normal winter to 40 in the severe winter, but the total number of convoys decreased from 185 to 154. This reduction was due to Class B icebreakers being generated instead of Class B icebreakers (Class B icebreakers can handle twice as many ships per convoy as can Class C icebreakers). For the normal winter, between 3 and 5 Class C icebreakers were required, while for the severe winter the icebreaker fleet ranged from 1 Class D and 4 Class C icebreakers to 4 Class B icebreakers.

8. Effect of Prohibiting Class C Icebreakers from Convoying - For Oil Can and Coal Shovel, restricting Class C icebreakers from convoying did not significantly reduce the number of icebreakers generated. For Coal Shovel, however, it did tend to replace each Class C icebreaker eliminated with an equal number of Class B icebreakers, indicating that the increased convoying capability of Class B icebreakers was not utilized. For the Seaway, the maximum generated icebreaker fleet changed from 11 Class C icebreakers to 1 Class C and 4 Class B icebreakers for period 6. At Taconite, for all periods, the average total number of icebreakers required decreased by 21%, with Class C icebreakers almost completely eliminated and 1 additional Class B icebreaker added for every 2 Class C icebreakers eliminated.

9. Effect of Increased SHP/Length Restriction - The removal of Class 5 laker vessels (SHP/lengths = 6.25) from the fleet reduced the icebreaking requirements significantly in all task commands. In Taconite, the number of direct assists dropped from 1032 to 671 and the number of convoys escorted dropped from 937 to 587. This resulted in a reduction of

the generated icebreaker fleet by more than 50%. In Oil Can the number of direct assists decreased from 102 to 11, resulting in a reduction in the number of icebreakers from an average of 5 icebreakers in periods 3 through 7 to an average of 1 icebreaker in periods 6 and 7. In Coal Shovel, with the exception of period 7, the number of required icebreakers decreased by a factor of 2 due to the total number of direct assists dropping from 573 to 337 and the elimination of 347 convoys. In the Seaway, the total number of direct assists decreased from 40 to 20 and the total number of convoys decreased slightly from 160 to 154, resulting in a reduction in icebreaking requirements by approximately one third.

10. Effect of Channel Clearing - The primary effect of channel clearing which, in run 9, was performed in reaches where convoying occurred, was to: (1) decrease the size of icebreakers required for convoying, and (2) increase icebreaker speeds which allowed each icebreaker to effectively handle more convoys, at times comprised of fewer ships due to ship arrival frequency. For Oil Can and Coal Shovel where there was no convoying, almost no effect from channel clearing was observed. In the Seaway, both the size and number of icebreakers were reduced. For example, in period 6, 8 Class C icebreakers were replaced by 5 Class C icebreakers with channel clearing. In period 7, 5 Class B icebreakers were replaced with 3 Class B icebreakers and 1 Class C. For Taconite, a similar condition occurred in that both the number and size of icebreakers were reduced. In period 8, the required 12 icebreakers (8 Class C and 4 Class B) were replaced by 7 icebreakers (5 Class C and 2 Class B).

RECOMMENDATIONS

1. The GL-SLS NAVIGATION SIMULATION should be kept current by revising the input data files and changing the basic rules and assumptions as required. We believe this simulation is an excellent planning tool which can be used as an aid to the U.S. Coast Guard in establishing their future icebreaking requirements and evaluating alternate icebreaker plans and concepts of operation, such as direct assistance, convoying, channel maintenance and channel ice clearing, as to their impact on extended commercial navigation operations and economics. In addition, the simulation can be used by the Corps of Engineers as a planning tool to aid in their assessment of the potential benefits and impacts of various proposed GL-SLS System improvements for normal navigation season operations as well as extended navigation season operations.

2. We also recommend that, as additional extended navigation season operations continue and more icebreaker operational data is gathered, additional validation runs be performed to ensure the continued credibility of the simulation.

3. To gain further insight and a more comprehensive understanding of the impacts on icebreaker requirements and commercial navigation operations and economics, we recommend that additional sensitivity runs be performed on:

   - Variations of fixed icebreaker fleets and home ports
   - Variations in channel clearing and preventive icebreaking
   - Variations in MRT mode conditions
   - Variations in ice conditions
   - Variations in low SHP/length restriction

4. During the course of modifying the simulation and conducting the runs, we found that the following revisions to the simulation should be considered:

   - Revise Fixed Fleet Mode to prohibit icebreakers from traveling over long distances within a task command, such as an icebreaker continually traversing Lake Superior between Duluth/Superior and the Soo.

   - Incorporate a probability basis for ships getting or not getting stuck rather than the current assumption of all ships of a given class getting stuck if their speed of advance is less than 2 mph; that is, apply a probability distribution which would vary linearly with the speed of advance between a probability of getting stuck equal to 1 at some designated speed, and a probability equal to 0.0 at some higher designated speed. In this manner, the "off-on" switch for all ships in a given class either being or not being stuck would be eliminated.

   - For ease of data analysis, revise the REPORT GENERATING MODEL to provide summary tables similar to those listed in Section 6.4 for each run.

2. INTRODUCTION

2.1 Objectives

The overall objective of this study was to develop a planning tool for use by the U.S. Coast Guard to aid in establishing their future icebreaking requirements for the Great Lakes-St. Lawrence Seaway (GL-SLS) Navigation System as a function of projected cargo tonnage, trade routes, winter severity, vessel ice transiting capabilities, vessel operating restrictions and alternate icebreaking plans and concepts of operation (direct assistance, convoys, channel maintenance, and channel ice clearing). More specifically, the objectives were to modify the existing GREAT LAKES-ST. LAWRENCE SEAWAY NAVIGATION SIMULATION so that it could be used as a tool to aid in:

- Determining Coast Guard icebreaker requirements for the Great Lakes-St. Lawrence Seaway.
- Determining benefits in terms of reduced commercial vessel transit time and shipping cost and increased fleet tonnage capacity derived from the presence of icebreakers.
- Determining the impact of user charges to help defray costs of icebreaking assistance and channel maintenance during extended navigation season operations.
- Determining the impact of establishing minimum ship operating requirements, such as SHP/length for ships operating during the extended season.
- Investigating proposed alternate icebreaking plans and concepts of operation (direct assistance, convoys, channel maintenance, and channel ice clearing).
- Examining different fleet mixes of icebreakers and icebreaking tugs and their assigned areas.
- Determining the impact of short term variations in ice conditions on icebreaking effectiveness and requirements.

2.2 Background

The existing GREAT LAKES-ST. LAWRENCE SEAWAY NAVIGATION SIMULATION was developed by ARCTEC for the North Central Division of the U.S. Army Corps of Engineers under Contract No. DACW-23-75-C-0043 [1]* and subsequently expanded for the St. Lawrence Seaway Development Corporation under Contract No. DOT-SL-70-467 [2] to model the movement of ships and cargo within the Great Lakes-St. Lawrence Seaway Navigation System and to and from world areas, during both the normal and winter navigation seasons. This existing simulation was developed as one part (Phase II) of a total program referred to as the GREAT LAKES-ST. LAWRENCE SEAWAY NAVIGATION SYSTEM STUDY, which was comprised of the following phases:

PHASE I: TRAFFIC FORECAST STUDY

A. Preliminary Traffic Forecast 1980-2040
B. Shipper Preference Study
C. Development of a CARGO FLOW MODEL

PHASE II: RATE AND COST STUDY

A. Normal Season
B. Extended Season

PHASE III: SYSTEM INTERRELATIONSHIP STUDY

A. System Capacity
B. System Optimization

In Phase I, the primary objective was to develop a method of estimating future traffic suitable for waterborne movement in the GL-SLS System. This phase consisted of a Preliminary Traffic Forecast of U.S. and Canadian general cargo, grain, and mineral bulk commodities for the years 1980-2040, followed by a Shipper Preference Survey and development of a CARGO FLOW MODEL. The output from Phase I were then used as input into Phase II (Development of the GREAT LAKES-ST. LAWRENCE SEAWAY NAVIGATION SIMULATION) to provide an estimate of the impact on annual vessel operating costs and the associated required freight rates.

Using the results of Phases I and II, an overall computer model of the GL-SLS System was to be developed in Phase III to study the system's capacity and to evaluate the potential benefits of proposed improvements. A conceptual flow diagram [3] depicting the model is given in Figure 2.1. The WINTER RATE STUDY contained in Figure 2.1 corresponds to the model (GL-SLS SIMULATION) described in this report. As seen from the flow diagram, the CARGO FLOW MODEL converts the hinterland cargo forecast information, length of the navigation season and initial rate and cost data into cargo forecast data. This cargo forecast data, in the form of cargo origin and destination data, along with the

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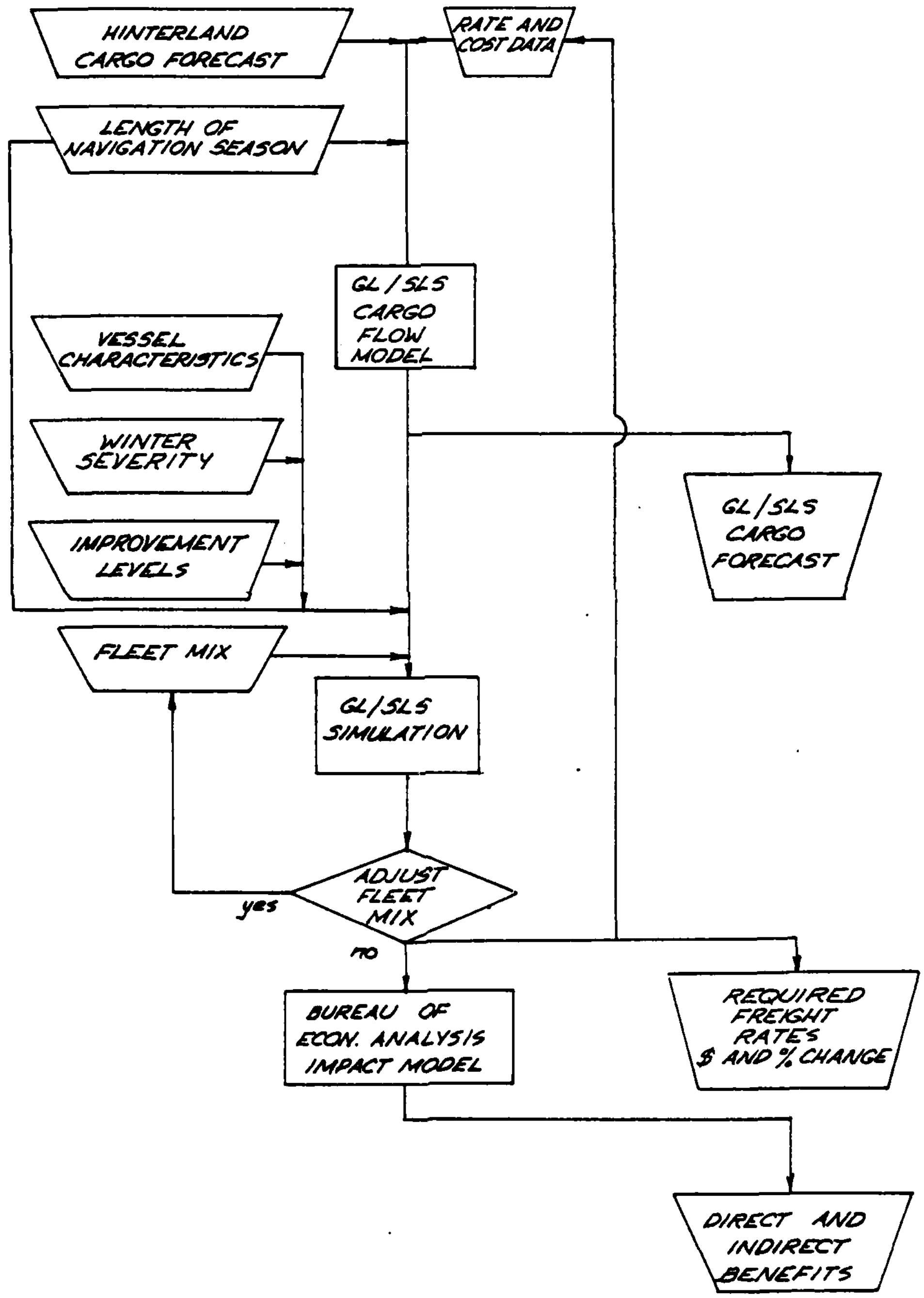
* Numbers in brackets denote references listed in Section 9 of the report.

FIGURE 2.1

CONCEPTUAL BLOCK DIAGRAM FOR TOTAL PROGRAM



length of the navigation season, fleet mix, vessel characteristics, winter severity, and improvement levels, is entered into the GL-SLS SIMULATION which models the movement of ships and cargo through the system and to and from overseas ports. The SIMULATION computes statistics for each class of ship operating on each route and converts these statistics into annual vessel operating costs and the associated annual required freight rates for each route. In simulating the movements of ships and cargo, the model incorporates the following interactions between ships and the system, as well as the interaction between the ships themselves:

- Port and lock limitations and constraints
- Draft limitations
- Speed limits
- Daylight only navigation
- Queues forming, expanding, and diminishing at lock and port facilities
- Increased transit, lockage, and port times due to presence of ice during extended season operations
- Ships getting stuck in ice and having to wait for icebreaker assistance
- Ships having to convoy and wait for icebreaker escort.

The Corps of Engineers model, as seen from the flow diagram, is an iterative one in which the output from the CARGO FLOW MODEL is required as input to the SIMULATION and vice versa. The program can therefore be thought of as a spiral in which several iterations are required to achieve a final solution. Where the spiral is entered is relatively unimportant as long as reasonable initial input data is available and a sufficient number of iterations are performed. Once a solution within the required accuracy is obtained, the annual required freight rates and annual vessel operating costs are fed back into the CARGO FLOW MODEL and the cycle is repeated until an overall solution is achieved within the desired accuracy limits on annual cargo throughput and required freight rates. The final results are then entered into the IMPACT MODEL of the Bureau of Economic Analysis (BEA) to determine the direct and indirect benefits.

2.3 Method of Approach

To accomplish the stated objectives, the method of approach was to modify the existing simulation in the following ways:

- Revised ice conditions data in the simulation to better reflect normal and severe winter conditions for light, moderate, and heavy commercial navigation.
- Developed and incorporated a complete set of icebreaker operating subroutines capable of modeling the following modes of icebreaking operations: preventive icebreaking, convoying, and direct assistance for vessels stuck in ice.
- Modified the simulation to include the capability for icebreaker user charges in vessel operating costs.
- Modified the simulation to generate icebreaker statistics, such as number of vessels assisted, total time assisting vessels, response time, and operating hours, to be used to assess icebreaker efficiency and cost of operations.
- Revised icebreaker characteristics in the simulation to better reflect existing, planned, and proposed icebreakers.
- Revised the program to permit two study options: in the first, a fixed fleet of icebreakers is defined; in the second, a maximum response time (variable with area of operation) is defined and the icebreaking fleet determined accordingly.
- Provided data files which can be modified to assess the effect of short term variations in ice conditions on the ability of the icebreaker fleet to maintain commercial navigation.
- Modified the computer simulation as needed to clearly identify all savings in commercial vessel transit times attributable to icebreaker operations when comparing simulation runs with and without icebreaker support.

Once the modifications were incorporated, the simulation was validated using U.S. Coast Guard icebreaking records for the 1975-1976 winter navigation

season. Upon completion of the simulation validation, a series of ten (10) runs, listed in Section 6.3, were performed and analyzed to assess the impact of winter severity, vessel restrictions, icebreaker fleet, use of convoys, and channel ice clearing. The results, along with the conclusions and recommendations drawn from these runs, are presented in Sections 6, 7, and 8 of this report.

3. DESCRIPTION OF GREAT LAKES-ST. LAWRENCE SEAWAY NAVIGATION SIMULATION

3.1 Overview

As stated in the Introduction, the GL/SLS NAVIGATION SIMULATION was developed initially as the Winter Rate Study [1] for the North Central Division of the U.S. Army Corps of Engineers. The purpose of this computer simulation was to model the movement of ships and cargo, during both the normal and winter navigation seasons within the Great Lakes-St. Lawrence Seaway System, and to and from overseas ports. In simulating the movement of ships and cargo, the model incorporated both the interactions between ships and the system, and the interactions between the ships themselves, such as:

- Port and lock limitations and constraints
- Draft limitations
- Speed limits
- Daylight only navigation
- Queues forming, expanding, and diminishing at lock and port facilities
- Increased transit, lockage, and port times due to presence of ice during extended season operations
- Ships getting stuck in ice and having to wait for icebreaker direct assistance
- Ship convoying with icebreaker escort through critical areas.

During the running of the simulation, statistics are compiled for each class of ship operating on each route. These statistics, along with vessel data, are converted into icebreaker performance measures, annual vessel operating costs, annual required freight rates, and performance measures for each route.

In order to develop a computer simulation which has sufficient detail to yield reasonable results while requiring a minimum of computer time, the total simulation model was divided into the following four individual models:

- ICE GROWTH MODEL
- SHIP SPEED GENERATING MODEL
- SHIP PROCESSING MODEL
- FREIGHT RATE/REPORT GENERATING MODEL

The relationship of these four models to one another and to the input data is illustrated by the block diagram shown in Figure 3.1. By dividing the total simulation model in this manner, repetitive calculations, such as determining the transit speed with which a particular vessel class traverses a given reach, need only be performed once and stored in a data file for use every time a ship of that vessel class traverses the reach. Each of these models is described briefly in the following subsections.

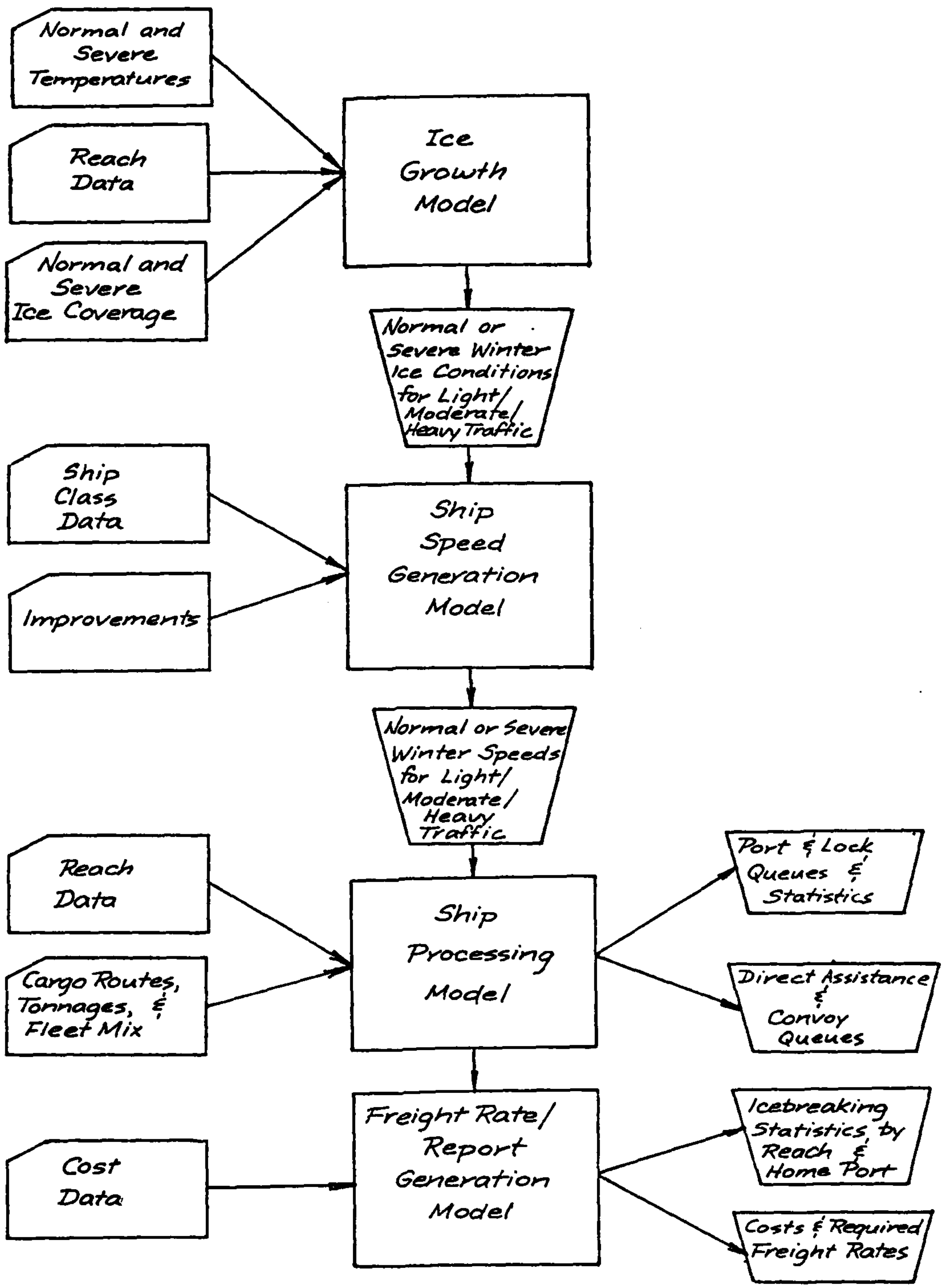


Figure 3.1. Conceptual Block Diagram for GL-SLS Navigation Simulation

3.2 Ice Growth Model

3.2.1 Purpose

For simulation runs that extend into winter operations, the purpose of the ICE GROWTH MODEL is to prepare a data file which contains

- Ice type as a function of level of traffic
- Ice thickness as a function of temperature, location, and level of traffic
- Channel width in a turn as a function of preventive icebreaking

in each reach for every two week time period. This data file is then used by the SHIP SPEED GENERATING MODEL to determine the speed of advance of each vessel class in each reach for every time period in the simulation. The calender dates of the simulation time periods are given in Table 3.1.

3.2.2 Method of Approach

As described in Section 4, ice conditions for every channel and lock reach are defined for each two-week time period in the simulation by dividing each reach into five (5) sections corresponding to the existence of different ice conditions along the length of the reach. Each of these sections, with the exception of the middle one (Section 3), is described by a length and the existing level ice thickness, refrozen brash ice thickness, and brash ice thickness. The middle section (Section 3) is reserved for open water and only its length is denoted.

The ice conditions for any reach and time period are thus defined by:

ICE CONDITIONS IN A REACH

Section 1

$L_1 \quad h_{1_L} \quad h_{1_{RB}} \quad h_{1_B}$

Section 2

$L_2 \quad h_{2_L} \quad h_{2_{RB}} \quad h_{2_B}$

Section 3 (Open Water)

L_3

Section 4

$L_4 \quad h_{4_L} \quad h_{4_{RB}} \quad h_{4_B}$

Section 5

$L_5 \quad h_5 \quad h_{5_{RB}} \quad h_{5_B}$

TABLE 3.1

CALENDAR DATES OF SIMULATION PERIODS

PERIOD	NORMAL YEAR 1975-76	SEVERE YEAR 1976-77
1	Normal Season	Normal Season
2	8 Dec - 21 Dec	6 Dec - 19 Dec
3	22 Dec - 4 Jan	20 Dec - 2 Jan
4	5 Jan - 18 Jan	3 Jan - 16 Jan
5	19 Jan - 1 Feb	17 Jan - 30 Jan
6	2 Feb - 15 Feb	31 Jan - 13 Feb
7	16 Feb - 29 Feb	14 Feb - 27 Feb
8	1 Mar - 14 Mar	28 Feb - 13 Mar
9	15 Mar - 28 Mar	14 Mar - 27 Mar
10	29 Mar - 11 Apr	28 Mar - 10 Apr

Note: Periods start on a Monday to coincide with ice data sources.

where

$$\left.\begin{aligned} L_i &= \text{length of subreach (mi)} \\ h_{iL} &= \text{thickness of level ice (in)} \\ h_{iRB} &= \text{thickness of refrozen brash (in)} \\ h_{iB} &= \text{thickness of unconsolidated brash (in)} \\ i &= \text{section} \end{aligned}\right\} i = 1, 2, 3, 4, 5$$

The selection of representative normal and severe winters was based on a comparison of cumulative freezing degree days with historical weather records for different portions of the Great Lakes area. In addition to the above criteria, it was required that recent winters be selected in order to obtain historical ice condition data as well as icebreaker support data during extended navigation season operations. The winters of 1975-76 and 1976-77 met the above conditions and were judged to be representative of normal and severe winters on the Great Lakes. In fact, as stated by Quinn and Leshkevich of GLERL* "...the 1975-76 winter season can be characterized as near normal for all of the Great Lakes.... The winter of 1976-77 was the fifth coldest in the past 200 years." [12, 13]. To define ice conditions, all available ice data for the winters 1975-76 and 1976-77 were gathered and analyzed to provide a description of ice conditions for a normal and a severe winter, respectively, on the Great Lakes-St. Lawrence Seaway. The sources of data included:

SLAR Ice Charts	- Prepared by USCG/NWS/NASA
Satellite Photographs	- Prepared by NOAA/NESS
Ice Condition Charts	- Prepared by Ice Forecasting Central, Department of the Environment, Canada
Great Lakes Ice Summaries	- Prepared by the Ninth Coast Guard District
"Great Lakes Ice Cover, Winter 1975-76"	- Prepared by George A. Leshkevich, NOAA Technical Memorandum, ERL-GLERL-12

This data provided an excellent method for estimating the type and extent of coverage on the Great Lakes-St. Lawrence Seaway during the two winters being analyzed. However, this data did not provide the needed values of level ice thickness, brash ice thickness, or refrozen brash ice thickness in the ship navigation channels. In order to make these estimates, separate mathematical models for level ice growth, brash ice formation in a navigation channel, and refrozen brash ice thickness were developed. Each of these models is described in detail below.

Level Ice Thickness Estimate - For each subreach in each time period, the level ice thickness is estimated using the traditional method of defining level ice thickness as a function of the square root of cumulative freezing degree days since the first formation of ice [4]:

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*Great Lakes Environmental Research Laboratory

$$h_{iLj} = \alpha \left[\sum_{m=k}^{j} \text{FDD}_m \right]^{1/2} = \left[h^2_{iL(j-1)} + \alpha^2\ \text{FDD}_j \right]^{1/2} \qquad (3\text{-}1)$$

where

h_{iLj} = level ice thickness for period j

α = freezing degree day coefficient for each reach

FDD_j = freezing degree days during period j

k = period K when ice first appeared

If the air temperature is above freezing, the ice will melt at a rate assumed directly proportional to freezing degree days expressed by:

$$h_{iLj} = h_{iL(j-1)} + (0.2187 \text{ X } \text{FDD}_i) \qquad (3\text{-}2)$$

Refrozen Brash Ice Growth Estimate - When a ship passes through an ice field, it leaves a mixture of broken ice pieces and water in its track. If the air temperature is below freezing, the water at the surface in the spaces between ice pieces will start to freeze. The crust, which forms at the surface, consists of old broken pieces frozen together by new ice, and is referred to as refrozen brash ice. Figure 3.2 depicts brash and refrozen brash ice in a ship track with level ice on both sides of the navigation channel.

The ice growth models assume that the air temperature is constant during each of the 14 day periods in the simulation. The ice growth models further assume that the ship transits along each reach are uniformly distributed in time within each time period. Utilizing these two assumptions, the refrozen brash ice thickness in a ship track can be calculated by the equation:

$$h_{Ri} = \alpha \left[\frac{\text{FDD}_i}{\text{NSPP}} \right]^{1/2} \qquad (3\text{-}3)$$

where

h_{Ri} = refrozen brash ice thickness during period i

NSPP = number of ship transits per period.

NSPP, the number of ship transits per period, is defined by the traffic level: light, moderate or heavy.

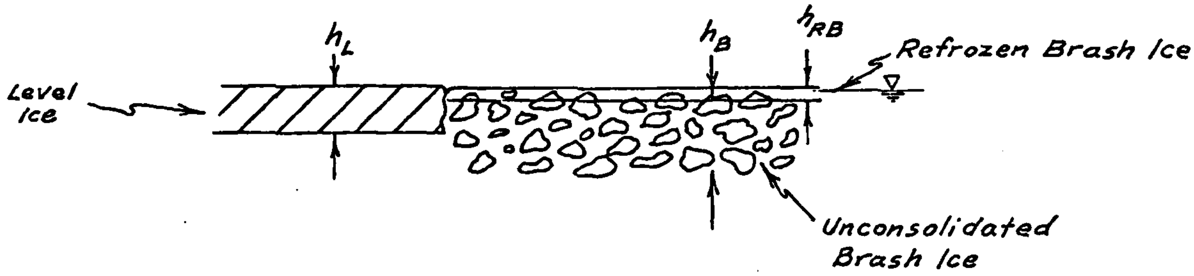

Figure 3.2. Broken and Refrozen Ice in a Ship Track

Unconsolidated Brash Ice Growth Estimate - As stated previously, when a ship passes through an ice field it leaves a mixture of broken ice pieces and water in its track. The amount of ice is the same as before the ship passage; however, the newly formed ice-water mixture occupies more volume than the ice alone did prior to the ship passage. The thickness of the mixture after a ship passes through a level ice field is:

$$h_B = \frac{h_L}{(1-\beta)} \tag{3-4}$$

where

h_B = unconsolidated brash ice thickness

β = porosity = $\frac{\text{volume of voids}}{\text{total volume}}$

In each case where the surface refreezes before the next ship comes along, each ship breaks up the refrozen crust and turns it into unconsolidated brash ice. Therefore, each succeeding ship sees a slightly thicker unconsolidated brash ice layer.

Ashton [5] and Michel and Lafleur [6] have proposed similar models for the growth of ice in a ship track. The model used in the simulation for growth of unconsolidated brash ice is based upon these two models, but incorporates the assumptions of constant temperature and uniform distribution of ships in a period.

The first ship in period i will encounter a total depth of ice slightly thicker than that left by the last ship in the previous period:

$$D_1 = \left[D_{Bi-1}^2 + \alpha^2 \; \frac{\text{FDD}_i}{\text{NSPP}} \right]^{1/2} \tag{3-5}$$

where

D_1 = depth of ice that the first ship in the period sees

D_{Bi-1} = depth of brash ice at the end of period i-1

$$D = h_R + h_B = \left[D_{Bi-1}^2 + h_{Ri}^2 \right]^{1/2} \tag{3-6}$$

The second ship in the period encounters additional ice thickness due to breaking up the refrozen crust and the ice growth under the broken pieces at the surface.

$$D_2 = \left[\left(D_1 + \frac{\beta h_{Ri}}{(1-\beta)} + \frac{\beta(1-\beta)}{(1-\beta)}\ ((h_{Ri}^2 + h_{Ri}^2)^{1/2} - h_{Ri})\right.\right. \tag{3-7}$$

$$\left.\left.\frac{\beta(1-\beta)^2}{(1-\beta)}\ (((2h_{Ri})^2 + h_{Ri}^2)^{1/2} - 2h_{Ri}) + \ldots\right) + h_{Ri}^2\right]^{1/2}$$

The long expression which makes the first squared term is, itself, composed of terms which represent different contributions to the growth of the ice. The first term, D_1, is the depth of unconsolidated brash ice sheet by the previous ship. The second term is the additional thickness due to breakup of the refrozen crust. The third term is the additional thickness due to the breakup of the ice forming under the first layer of ice pieces. The fourth term is the additional thickness due to the breakup of the ice forming under the second layer of ice pieces.

As the total amount of ice grows, more ice floats above the waterline due to the density difference between ice and water. As these ice pieces emerge from the water, they act as an insulator and slow down the rate at which new ice is generated. Effectively, a layer of ice is added above the waterline. The effective thickness of this layer, h_{ue}, is:

$$h_{ue} = D(1 - \rho_i/\rho_w)\ (1 - \beta) \tag{3-8}$$

Equation (3-7) changes to:

$$D_2 = \left[\left(D_1 + \frac{\beta}{(1-\beta)}\ ((h_{ue}^2 + h_{Ri}^2)^{1/2} - h_{ue}) +\right.\right.$$

$$\frac{\beta(1-\beta)}{(1-\beta)}\ (((h_{ue} + h_{Ri})^2 + h_{Ri}^2)^{1/2} - h_{ue} + h_{Ri}) + \tag{3-9}$$

$$\left.\left.\frac{\beta(1-\beta)^2}{(1-\beta)}\ (((h_{ue} + 2h_{Ri})^2 + h_{Ri}^2)^{1/2} - (h_{ue} + 2h_{Ri}))\right)^2 + ((h_{ue}^2 + h_{Ri}^2)^{1/2} - h_{ue}^2)\right]^{1/2}$$

The calculation of the unconsolidated brash ice depth by this method is an iterative procedure. Due to the insulation effect, the refrozen brash ice thickness is not constant as the insulating layer grows. The refrozen brash ice thickness that the ship experiences is no longer defined by equation (3-3) but rather by:

$$h_{Ri} = (h_{ue}^2 + h_{Ri}^2)^{1/2} - h_{ue} \qquad (3\text{-}10)$$

Melting of the unconsolidated brash ice is treated much the same as the melting of the level ice. Since the temperature is above freezing, no refrozen brash ice can form and the unconsolidated brash ice melts according to:

$$h_{Bi} = h_{Bi-1} + (0.2187 \times \mathrm{FDD}_i)/(1 - \beta) \qquad (3\text{-}11)$$

3.3 Ship Speed Generating Model

3.3.1 Purpose

The purpose of the SHIP SPEED GENERATING MODEL is to:

- Convert the ship characteristics, reach characteristics, ice conditions, and improvement levels, into the speed for each class of ship in each reach for open water (during normal season operations) and for every two-week season extension period. This information is stored in three (3) data files for light, moderate and heavy traffic levels.
- Generate an increased service time factor based on ice conditions for each port and lock facility for every two-week season extension period.
- Determine the maximum ship length and maximum allowable ship draft permitted to move from each port to every other port.
- Assemble the data in an appropriate format required by the SHIP PROCESSING MODEL.

In addition, the SHIP SPEED GENERATING MODEL also indicates in which reaches a particular class of ship will become stuck in ice. Delay times due to a ship's becoming stuck and then waiting for icebreaker assistance are not determined in this model but rather in the SHIP PROCESSING MODEL, since these delays are related to the availability of icebreaker support. Similarly, delay times due to ships waiting in queues for a port or lock facility are also determined in the SHIP PROCESSING MODEL.

3.3.2 Method of Approach

The average speed of advance for a particular class of ship to traverse a given reach is equal to the total length of the reach divided by the transit time required for the ship to traverse each section of the reach; that is:

$$V_{\text{average}_i} = 88.00 \; \frac{d_1 + d_2 + d_3 + d_4 + d_5}{t_1 + t_2 + t_3 + t_4 + t_5} \qquad (3\text{-}12)$$

where

V_{average_i} = average speed of advance (fps) for a ship to traverse the ith reach

t_j = transit time (minutes) for a ship to traverse the jth section of the reach (j = 1, 2, 3, 4, 5)

d_j = length (miles) of the jth section of the reach (j = 1, 2, 3, 4, 5)

To use equation (3-12), t_j must be determined. In general, t_j is a function of the ship's thrust capability, its resistance characteristics, the ice conditions, river current, winds, visibility, and imposed speed limits. The delaying effects of high winds and low visibility are accounted for by using an average weather delay factor of 1.08 based on historical data provided by United States Steel Corporation, while the effect of river current has been neglected. Equation (3-12) can therefore be expressed as:

$$\begin{aligned} t_j &= \left(88.0 \frac{d_j}{V_j}\right) \times 1.08 \\ &= 95.04 \frac{d_j}{V_j} \end{aligned} \qquad (3\text{-}13)$$

where

V_j = average speed of advance of a ship traversing the jth section of the reach neglecting weather delays (fps)

One of the basic assumptions in developing the simulation is that ships would attempt to proceed at their maximum speed capability provided it is less than any imposed speed limit. If a ship's maximum speed capability is greater than the speed limit, the ship would reduce its speed accordingly. Expressed mathematically,

$$V_j = \begin{cases} V_{\text{max}}: & \text{if } V_{\text{max}} < V_{s\ell} \\ V_{s\ell}: & \text{if } V_{\text{max}} < V_{s\ell} \end{cases} \qquad (3\text{-}14)$$

or

$$V_j = \text{minimum of} \begin{cases} V_{\text{max}} \\ V_{s\ell} \end{cases}$$

where

V_{max} = maximum speed capability of the ship in the jth section of reach (fps)

$V_{s\ell}$ = imposed speed limit

For steady state motion, the available thrust of a ship $T(V)$, is equal to the ship's resistance, $R(V)$, where both the thrust and resistance are functions of the ship's speed:

$$T(V) = R(V) \tag{3-15}$$

To determine the thrust-speed relationship for a given ship, the propulsion system of the ship must be analyzed. Most ships, with the exception of ice-breakers or ships equipped with controllable pitch propellers, can be assumed to operate along constant torque curves independent of propeller RPM. Ice-breakers, because of their need for extra thrust capability at low speeds, and ships equipped with controllable pitch propellers operate along constant horsepower curves permitting higher torques to be attained at lower speeds. Using these assumptions, the thrust-speed relationships can be determined from representative propeller curves* for the following typical propulsion systems:

Steam Turbine Propulsion System

$$T(V) = (1.59-0.398\ (V/V_{design})-0.192\ (V/V_{design})^2)T_{design} \tag{3-16}$$

Diesel Propulsion System

$$T(V) = (1.32-0.196\ (V/V_{design})-0.124\ (V/V_{design})^2)T_{design} \tag{3-17}$$

Class D Icebreakers

$$T(V) = (2.21-1.06\ (V/V_{design})-0.140\ (V/V_{design})^2)T_{design} \tag{3-18}$$

Class C Icebreakers

$$T(V) = (1.49-0.206\ (V/V_{design})-0.284\ (V/V_{design})^2)T_{design} \tag{3-19}$$

Class B Icebreakers

$$T(V) = (2.08-1.02\ (V/V_{design})-0.060\ (V/V_{design})^2)T_{design} \tag{3-20}$$

* Icebreaker propeller performance is based on analysis of the MACKINAW, WTGB and 110's propeller data provided by USCG. Laker and salty propeller performance is based on an analysis of propeller data provided by U.S. Steel and MARINER CLASS VESSEL, respectively.

where

$$T_{design} = 550 \frac{(P.C.)\ (shp)}{V_{design}} \tag{3-21}$$

T = thrust of ship (pounds)

T_{design} = design thrust (pounds)

V = speed of ship (fps)

V_{design} = design speed of ship (fps)

$P.C.$ = propulsive coefficient $= \eta_O \cdot \eta_R \cdot \eta_H \cdot \eta_T$

shp = installed rate of shaft horsepower

η_O = propeller efficiency = 0.57

η_R = relative rotative efficiency = 1.0

η_H = $1\text{-}t/1\text{-}w$ = hull efficiency = 1.0

η_T = transmission efficiency = .98

These relationships are presented graphically in nondimensional form in Figure 3.3.

Resistance of a given ship is a function of the ship's characteristics, its speed, and the ice conditions (type and thickness). For the purposes of this simulation, the resistance of a given vessel is assumed equal to:

$$R_T = R_{OW} + R_{LI} + R_{RB} + R_B \tag{3-22}$$

where

R_T = total resistance (pounds)

R_{OW} = open water resistance (pounds)

R_{LI} = level ice resistance (pounds)

R_{RB} = refrozen brash ice resistance (pounds)

R_B = brash ice resistance (pounds)

As a first order approximation, the open water resistance is assumed to obey a velocity squared relation passing through the design-speed point.

$$R_{OW} = T_{design} \left(\frac{V}{V_{design}} \right)^2 \tag{3-23}$$

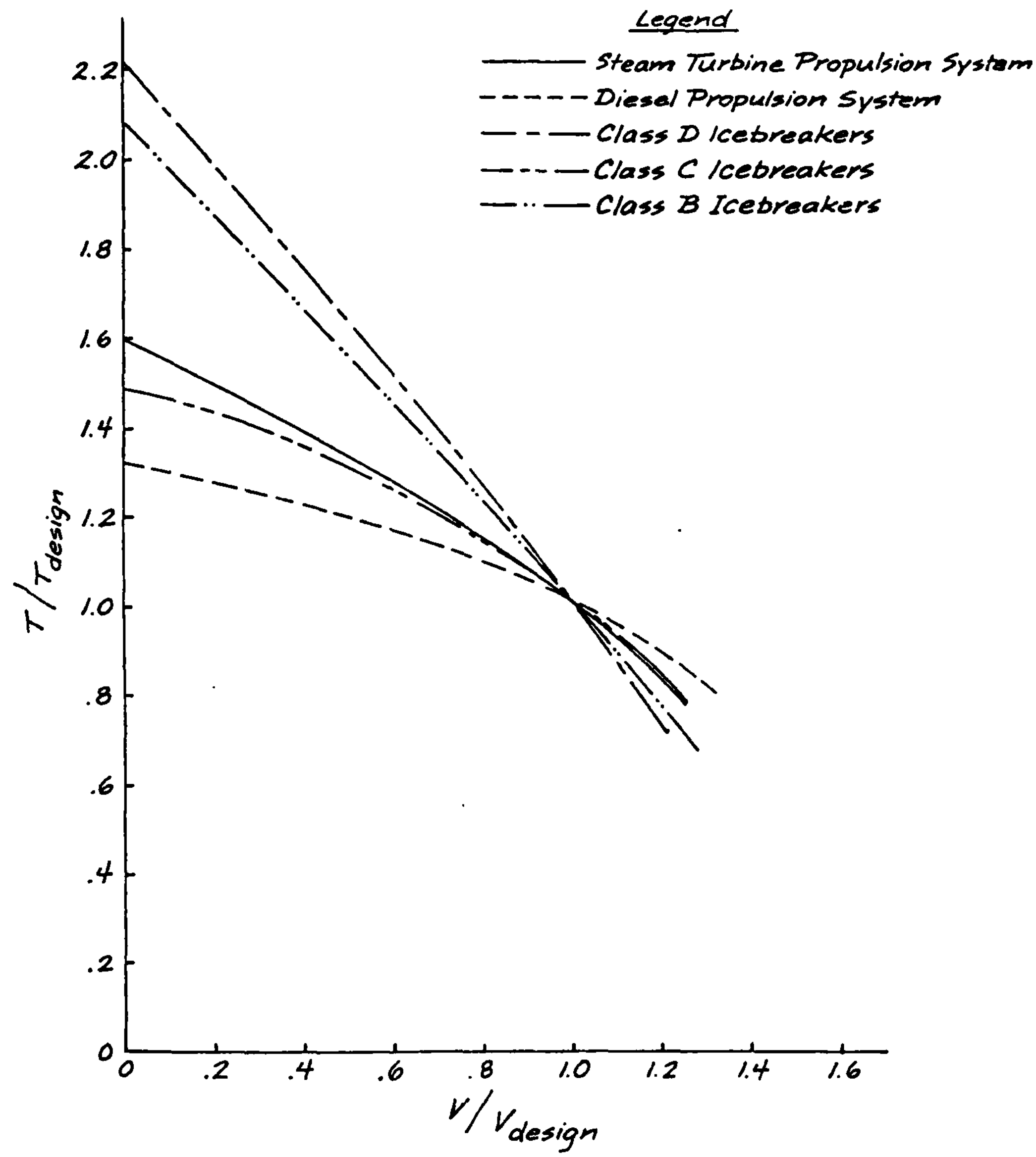

Figure 3.3. Thrust - Velocity Relation

where

T_{design} = design thrust required to overcome the resistance at design speed (pounds)

V_{design} = design speed (fps)

From model and full-scale resistance tests of the MACKINAW, WIND CLASS, WGTB, RYERSON, and NEW 1000' GL BULK CARRIERS, the resistance of ships in level ice, brash ice, and refrozen brash ice are estimated to be:

<u>Level Ice</u>

$$R_{LI} = \rho_w g B h_{LI}^2 \Big[(0.273 + 1.96\mu_0)(1 + 4.51f) + (0.0011 + 0.0116\mu_0^2/\eta_2)(1 + 2.92f)\left(\frac{V}{\sqrt{gh_{LI}}} \times \frac{\sigma_f}{\rho_w g h_{LI}}\right) \Big] \quad (3\text{-}24)$$

<u>Refrozen Brash Ice</u>

$$R_{RB} = 0.8\, R_{LI} \Big|_{h_{LI} = h_{RB}} \quad (3\text{-}25)$$

<u>Brash Ice</u>

$$R_B = \rho_w g B h_B{}^2 \left[0.320 + 1.51\mu_0 + \left(0.0369 + 0.0745 \frac{\mu_0{}^2}{\eta_2}\right) \frac{V^2}{gh_B} \right] \quad (3\text{-}26)$$

where

g = acceleration of gravity = 32.2 ft/sec^2

ρ_w = mass density of water = 1.94 slugs/ft^3

σ = flexural strength of ice = 18,000 psf

f = hull-ice friction factor = 0.25

h_{LI}, h_{RB}, h_B = level ice, refrozen brash ice, and brash ice thickness (ft)

μ_0, η_2 = hull shape geometric coefficients (obtained from analysis of vessel lines drawings)

		μ_0	η_2
Ocean-Going Vessels		2.06	5.53
Lakers		5.56	1.94
Icebreakers:	Class B	1.45	2.85
	Class C	1.45	2.96
	Class D	1.61	2.79

It should be noted that while equation (3-22) shows total resistance to be additive of the independent ice resistance components, the current state-of-the-art in predicting ice resistance has not proven or disproven this assumption. It is felt, however, that this assumed additive condition provides a good first approximation since in the limit the total resistance reduces to the individual components. For example, if there is no ice, then the total resistance equals the open water resistance and similarly if the brash ice thickness and refrozen brash ice thickness are zero, the ice resistance equals that of the level ice resistance. The only discrepancy occurs in that the open water resistance has been incorporated twice when the ship is operating in ice. While this gives a slight overestimate to the total resistance, the current-state-of-the-art in ice model testing has not developed a verified methodology to remove the open water resistance portion from the total measured resistance. Thus equation (3-22) is somewhat conservative, predicting a slightly higher resistance than one would expect in the real world. The open water resistance R_{OW} is included in equation (3-22) to enable the total resistance to be a continuous function at zero ice thickness (open water); expressed mathematically:

$$R_{OW} = \lim_{h \to o} \Big| (R_T) \tag{3-27}$$

In ice, the error introduced by including open water resistance twice is slight since ice resistance is much greater than R_{OW}.

Since both $T(V)$ and $R(V)$ are of quadratic form, equation (3-15) can be solved for the ship's maximum speed capability (V_{max}) in the ith section of the reach using the standard quadratic formula. The procedure is illustrated graphically in Figure 3.4. In solving this quadratic equation, two roots are obtained, consisting of positive and negative real roots, two negative real roots, or two complex roots, depending on the value of ice thickness for a given ship. If positive and negative real roots are obtained, the ship can proceed through the ice at a speed equal to the positive root, while the negative root is an extraneous solution to the equation. If two negative real roots or two complex roots are obtained, the ice is too thick for the ship to proceed through; that is, the ship does not have enough available thrust to overcome the resistance and its speed of advance will therefore correspond to zero. In practice, a minimum speed of advance of approximately 2 mph exists below which ships will not proceed and can be assumed stuck. Thus, if V_{max} is less than 2 mph, the ship is assumed to be stuck in ice and an icebreaker must be called to free the ship. If this occurs, the speed of advance of the ship is set to the speed in the remaining sections of the reach and an appropriate stuck code is added to the indicated speed.

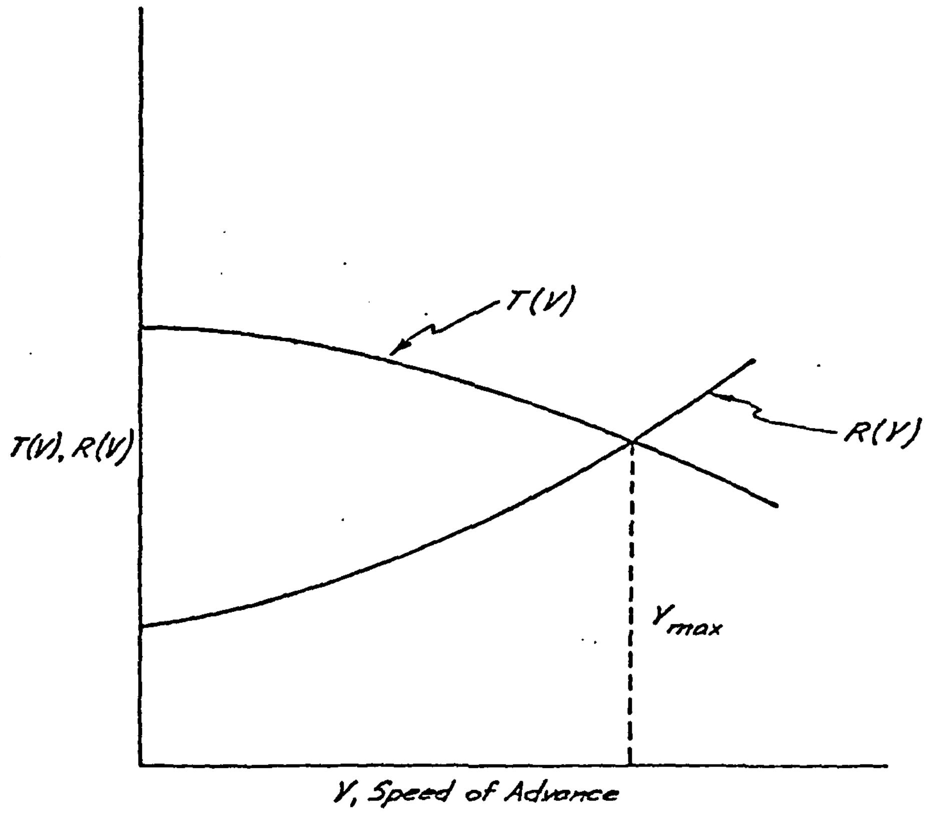

Figure 3.4. Typical Thrust and Resistance Characteristics

In addition to transit times, delay factors are calculated for each port and lock facility to indicate increased service time due to the following problems caused by the presence of ice:

- Turning in port basins
- Maneuvering into docks
- Need for ice lockages
- Removal of ice from lock walls
- Removal of ice from gate recesses

The problems associated with locks operating during winter are discussed in detail in reference [7]. These delays are assumed to be proportional to the ice thickness existing at the facility and to increase linearly at the rate of 1% per inch of ice based upon the results from the SPAN Study [7, 8] and discussions with fleet operators.

Thus,

$$f_{\text{delay}} = 1.0 + h/100. \tag{3-28}$$

where

f_{delay} = delay factor

h = ice thickness (inches) $= h_{LI} + h_{RB} + h_B$

Another ice problem which can restrict the movement of large ships in river reaches is their capability to maneuver around a turn in a river in a broken ice channel. The computer program simulates a ship becoming stuck in a tight turn by comparing the broken channel width required by the vessel to negotiate the turn to the radius of the turn as shown in Figure 3.5. Also shown in the figure is the effect on the turn radius of preventive icebreaking expressed as the widening of the turn versus the number of preventive icebreaker transits per period. It is assumed that the channel is widened from 150 ft by one-third of the icebreaker's beam per transit. The preventive icebreaking is simulated in the Ice Growth Model, which outputs the broken channel width for each reach by period, along with the ice conditions. The Speed Generating Model flags any vessel class that will become stuck in a given turn. The actual freeing of the stuck ship by an icebreaker is performed in the Ship Processing Model, which calculates how many passes of an icebreaker will be required to meet the minimum turn width, assuming the broken channel is widened one icebreaker beam per transit.

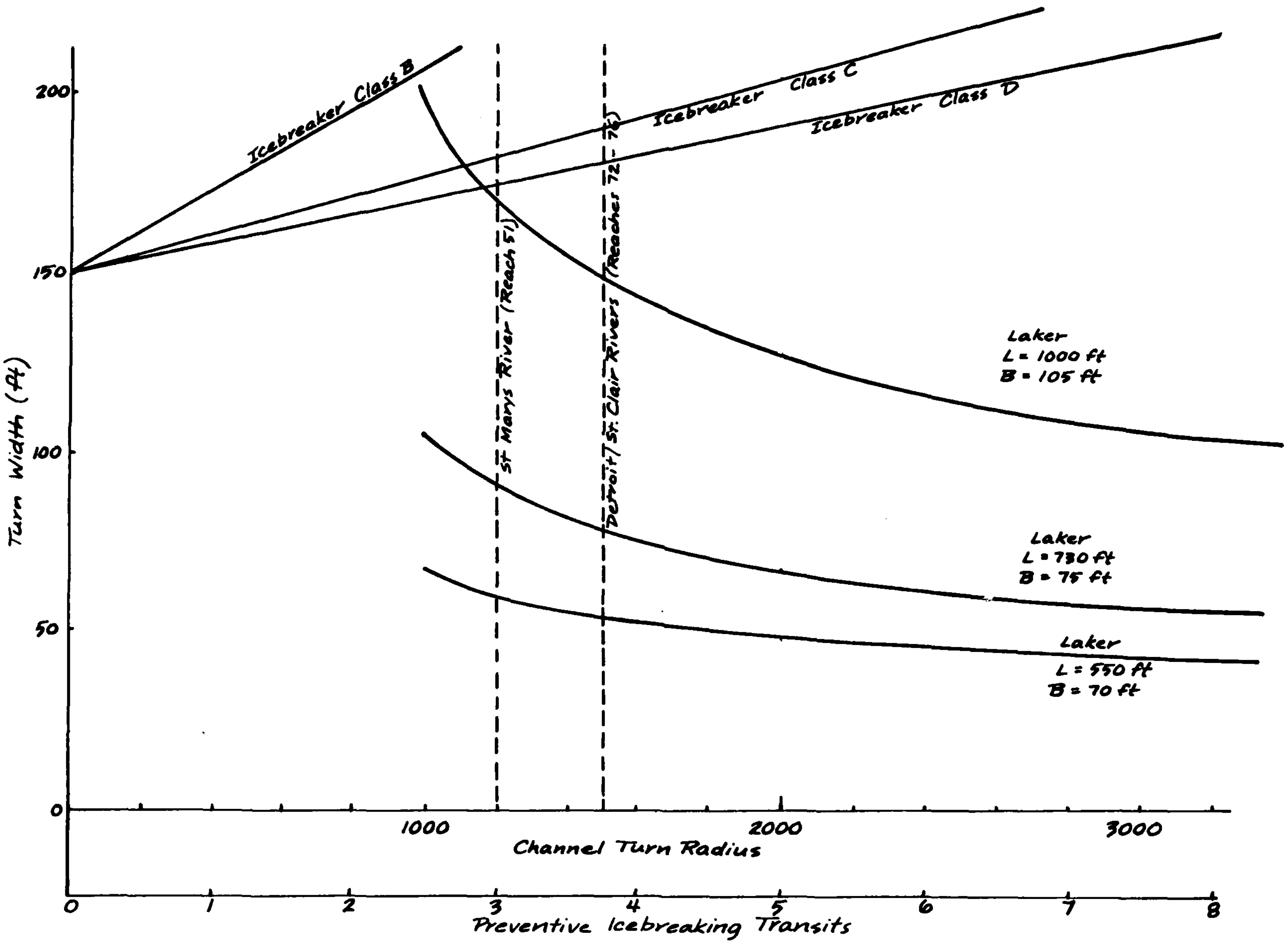

Figure 3.5 Required Turn Width vs Channel Turn Radius and Turn Width vs Preventive Icebreaking Transits

3.4 Ship Processing Model

3.4.1 Purpose

The SHIP PROCESSING MODEL uses the output from SHIP SPEED GENERATING MODEL, cargo origin and destination data, fleet mix, ship and reach characteristics, and improvement levels, to simulate the movement of ships and cargo while compiling the following statistics for each vessel class on every route for normal season operations and for every two-week season extension period.

- Tons of cargo transported
- Time underway with cargo
- Time stopped with cargo
- Total number of trips
- Number of trips made by ships equipped with bow thrusters
- Number of trips made by self-unloaders
- Time underway during empty backhaul
- Time stopped during empty backhaul
- Number of trips through the Seaway with cargo
- Number of trips through the Seaway without cargo
- Number of trips through the Welland with cargo
- Number of trips through the Welland without cargo
- Icebreaker assistance and convoy statistics

In processing ships from port to port, queues at ports and locks are allowed to form, expand, and diminish as necessary. The time spent in a queue waiting to be serviced is allocated to the route the ship is transiting. Similarly, when a ship becomes stuck and requires icebreaker assistance, the ship's waiting time is allocated to its current route. If an icebreaker is not immediately available, this additional waiting time is included.

3.4.2 Method of Approach

In order to meet the cargo tonnage criteria, ships are dispatched from port of origin at a required frequency rate and then proceed toward their port of destination. In the process, they obey the following basic rules and assumptions.

Commercial Ships

1. All ships in the fleet are represented by specific ship classes whose properties are specified for typical ships.

2. All ships attempt to maintain their maximum capable speed at all times except where speed limits exist.

3. A ship's maximum speed capability is determined by equating the ship's thrust capability to its resistance characteristics.

4. Ship delays due to bad weather are accounted for by decreasing the speed by a weather delay factor based on historical data.

5. A ship may be stuck due to resistance or it may become stuck because it is too long to turn within the required radius of a given channel width.

6. A ship is assumed to be stuck due to resistance if its maximum capable speed of advance is less than 2 mph in any subreach.

7. A ship is said to become stuck at the upper end of the reach, at the lower end of the reach, or both. This information, and how the ship became stuck, is encoded into the speed.

8. No accidents involving ships are assumed to occur in the system and no time delays due to accidents are considered.

9. All ships observe winter draft restrictions during extended season operations.

10. All lakers are assumed to lay-up at the end of the navigation season, while all ocean-going ships are assumed to operate elsewhere.

11. All ships are treated on an equal basis.

12. All ships operate only during daylight hours in areas where nighttime navigation is prohibited.

13. Once stuck, a ship calls on an icebreaker for assistance and waits until the icebreaker arrives at the ship's location.

14. If an icebreaker is not available and a ship becomes stuck, the ship must wait until one becomes available.

15. Ships are "created" by the simulation on a frequency basis as required to carry the specified tonnage on a particular route. Ships complete a round trip on a specified route, and are then "destroyed" by the simulation.

16. The number of vessels in the system floats according to the delays encountered since the tonnage to be carried is fixed.

17. Ships queue up at ports and locks and are serviced on a first-come first-served basis.

18. The frequency of ship generation varies as a function of time to simulate the seasonal tonnage variation that occurs with a fixed fleet as transit times increase during the extended season.

19. The speed of a ship in a reach depends on the type of ice conditions (level ice/brash ice with thick refrozen crust/thicker brash ice with thin refrozen crust) which, in turn, depends on the level of traffic (light/moderate/heavy).

20. The level of traffic for a given reach in any period is determined by the number of ship transits in the previous period: 0-2 light, 3-30 moderate, 31-∞ heavy.

21. Lakers are assigned to one route (origin/destination/commodity grouping) or two routes if on a triangular pattern. One round trip is made which includes an empty backhaul.

22. Salty General Cargo ships follow preassigned itineraries, spending two days in each port of call in the Great Lakes-St. Lawrence Seaway System and 2.5 days in the overseas ports.

23. Ships are routed only to ports which can accommodate their length.

24. The ship's draft is adjusted to meet the minimum requirements of the origin or destination.

25. Ships cannot go through locks which are shorter than their length.

Icebreakers - General

1. Icebreakers are assigned to one of seven task commands. In the fixed fleet mode, each icebreaker is free to respond anywhere within the task command. In the maximum response time mode, an icebreaker may respond only in reaches that have the same designated home port as the icebreaker.

2. When released from a specific task, an icebreaker is assigned to a direct assistance (DA) task, to escort a convoy, or to proceed back to home port reach-by-reach if not needed.

3. When both convoy and DA queues are waiting to be processed, the icebreaker is assigned to the ship which has been waiting the longest.

4. Icebreaker transits through reaches containing locks do not include lock queuing time since it is assumed icebreakers will be given top priority and will be locked through ahead of commercial vessels.

5. An icebreaker becomes stuck if its speed is less than 5 mph in any subreach. A ramming speed of 2 mph is then used.

6. If an icebreaker must ram in any subreach, a flag is encoded into the speed.

Icebreaker Selection and Response

1. When selecting an icebreaker for a task, two decision criteria are used: icebreaker capability and response time, as defined in rules and assumptions associated with convoying and direct assistance. In the fixed fleet mode, the *soonest capable* icebreaker is selected. A class is capable by default if the task command has no icebreakers of a higher class. In the MRT mode, the *lowest capable* class is selected.

2. If it is at its home port, an icebreaker's response time includes a standby time which is specified on a class basis (for production runs all icebreakers were assumed on an alert status and the standby time was input as 15 minutes).

3. When looking for an icebreaker for direct assistance duty, the convoy queues first have icebreakers "reserved" for all ships arriving within 12 hours. This gives priority to the convoys based on the assumption that a ship's master can radio ahead the ETA for a convoy point, whereas he would not be predicting where and when his ship will get stuck in the ice and require direct assistance.

Icebreaker Convoying

1. An icebreaker is "capable" of responding to a convoying task if the icebreaker does not have to ram through any of the reaches comprising the convoy route and if the time to transit the convoy route is less than the maximum endurance for that class icebreaker.

2. The icebreaker escorts the convoy at 80 percent of the calculated speed in each reach of the convoy route.

3. All ships in the convoy travel at the same speed as the icebreaker.

4. Convoys begin and end at reach nodes.

5. The escorting icebreaker is freed as soon as it completes the convoy route.

6. No ships will get stuck while traveling in a convoy.

7. After the icebreaker transit time to a convoy point is computed, it is decremented by the amount of time that the icebreaker has been free to account for icebreakers having been reserved for convoy duty. In this manner, the simulation models the assumption that task commands have prior knowledge of upcoming convoy requirements.

8. The following algorithm is used to determine if and when a convoy will leave. A convoy is checked for processing whenever a ship arrives at the convoy point and whenever an icebreaker in the same task command becomes free. If, at the time the icebreaker arrives at the convoy, the queue has enough ships to meet or exceed the escort capacity of the icebreaker, the convoy is deemed ready to leave. In addition, if at the

time the icebreaker arrives, the first ship in the queue has waited longer than its maximum allowable delay, the convoy is deemed ready to leave. In the fixed icebreaker fleet mode, this delay is equal to six hours; in the maximum response time mode, it is equal to the maximum response time of the downstream reach.

9. The size of a convoy is the number of ships in the convoy queue at the time the icebreaker arrives or the escort capacity of the icebreaker, whichever is less.

Icebreaker Direct Assistance - General

1. An icebreaker is "capable" of assisting a stuck ship if the icebreaker does not have to ram in the same reach that the ship is stuck in.

2. Each reach has four possible "stuck points". Points 1 and 4 are at the reach nodes; points 2 and 3 are 20% of the reach length from the nodes.

Icebreaker Direct Assistance - Ship Stuck Due to Resistance

1. The direct assistance deployment time when a ship is stuck due to resistance includes breakout time, which is defined as the time for the assisting icebreaker to travel ten miles in level ice in the reach that the ship is stuck in (maximum time is four hours). Breakout mileage is not included in the statistics.

2. Once the ship is free, the icebreaker escorts the ship to the end of the reach, traveling at 80 percent of its calculated speed in that reach.

3. The escorting icebreaker is deallocated when one of the following conditions are met:

   - a convoy point is reached
   - a port is reached
   - the next reach is passable by the ship without escort, or
   - the icebreaker reaches the task command boundary.

Icebreaker Direct Assistance - Ship Stuck in a Turn

1. Direct assistance deployment time for this case includes breakout time, which is defined as the time for the icebreaker to make the number of passes required to sufficiently widen the turn using the speed in level ice, assuming that the turn is widened one beam width each pass (maximum time is four hours).

2. The icebreaker is freed as soon as the ship is broken out of the turn.

Maximum Response Time (MRT) Mode*

1. The value of the maximum response time is input data specified by reach. (Note that this time must be greater than the time required for an icebreaker to get to the reach from the nearest home port.)

2. The lowest capable class of icebreaker is selected for a task (even if a higher class icebreaker has a shorter response time) to ensure that a minimum number of large icebreakers are created in the MRT mode.

3. When an icebreaker must be created to meet the maximum response time for a specific task, the lowest capable class is chosen and assigned to the nearest home port.

4. In the MRT mode, a free icebreaker is not deployed if it cannot reach its destination by the time the waiting ship has passed its maximum delay time.

5. The icebreaker fleet is zeroed at the beginning of each period, and grows as required to meet the demands for assistance.

Icebreaker Statistics

1. Statistics accumulated by reach reflect icebreaker escort (either direct assistance or convoy) within each reach.

2. Statistics accumulated by commercial vessel route include the time required for the icebreaker to get to the point of assistance from wherever it was when it was called.

3. Statistics accumulated by icebreaker class/task command include time getting to the point of assistance and returning to home port, as well as time for the assistance itself.

4. The direct assistance and convoy counters are incremented when the request is processed, not when it is requested.

Lock Reaches

1. Night operations are permitted except where restricted.

2. Ships are locked through in a manner which maximizes the lock's utilization.

3. If queues exist on both sides of the lock, the lock alternates in processing upbound and downbound ships.

4. Ships are processed out of each queue on a first-come first-served basis.

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* The MRT mode is described in detail as to its logic in the USERS MANUAL AND DOCUMENTATION in subroutines NEWIB, IBFREE, STKVS, PROSTK, PROCVY, ALLOC, ICEBRK, and CAPBLE.

5. If a queue exists on one side of the lock and the time of arrival of a ship at the other side of the lock is less than the turnback time of the lock. the lock waits to process the arriving ship. Otherwise, it turns back to process the next ship in the queue.

6. Only one ship at a time is locked through.

7. Locking times are assumed to increase equally for all classes of ships at the rate of one percent for each inch of ice existing in the reach.

Port Reaches

1. Port facilities are assumed to operate 24 hours a day.

2. Ships are loaded (unloaded) on a first-come first-served basis.

3. Ships are loaded with only one type of cargo at a time.

4. Stockpiles are assumed to exist at all ports of origin and all ships are loaded to capacity or to some draft limitation with the exception of general cargo ships.

5. Stockpiles are assumed to exist at all ports of destination and all ships are unloaded completely with the exception of general cargo ships.

6. General cargo ships are loaded and unloaded depending on the cargo destined for each port.

7. The port turnaround times are assumed to increase equally for all classes of ships at the rate of one percent for each inch of ice in the next downbound reach.

8. Ocean-going ships carrying grain stop in Baie Comeau to top-off before proceeding overseas.

Channel Reaches

1. Ships are not permitted to exceed a speed limit if one exists in a particular reach.

2. Passing is permitted in all reaches.

3. Night operation is permitted except in areas where restricted.

3.5 Freight Rate/Report Generating Model

3.5.1 Purpose

The FREIGHT RATE/REPORT GENERATING MODEL translates the statistics collected by the SHIP PROCESSING MODEL, along with vessel data, into the following icebreaker statistics, vessel operating costs, performance measures, and required freight rates.

ICEBREAKING DATA

- Direct assistance queue size by task command every 2 days (7 times per time period)
- Convoy queue size by direction every 2 days (7 times per time period)
- Icebreaker statistics by icebreaker class, task command, home port, and reach for every time period:
    - number of icebreakers
    - channel clearing (inches/period)
    - preventive icebreaking (hours/period)
    - number of direct assists
    - hours of direct assists
    - miles of direct assists
    - direct assistance average response time (hours)
    - direct assistance maximum response time (hours)
    - hours of convoys escorted
    - miles of convoys escorted

VESSEL TRADE ROUTE DATA

For each route and every time period, the following information is output on a cumulative basis for the fleet on each route as well as for each individual ship class:

- Total tonnage
- Time underway (domestic and world-wide)
- Time stopped (domestic and world-wide)
- Number of trips (total, and broken into ships with bow thrusters and ships that are self-unloaders)
- Crew Costs
- Maintenance and repair costs
- Store and supply costs

- Insurance costs
- Overhead costs
- Towing costs
- Lay-up charges
- Fuel costs
- Gallons of fuel consumed
- Tolls
- Total operating costs
- Operating cost per ton
- Operating cost per hour
- Operating cost per ton-mile
- Revenues per ton-mile
- Taxes per ton-mile
- Depreciation per ton-mile
- Profit per ton-mile
- Required freight rate (dollars/ton)
- Per-unit required freight rate (normalized to the normal season value)
- Revenue ton-miles (ton-miles on which cargo was carried)
- Total miles with cargo
- Total miles backhaul
- Dollar-miles (the value of the cargo times distance moved)
- Average trip time per trip (including loading/unloading time)
- Average trip time per ton-mile (including loading/unloading time)
- Average length of haul (miles)
- Icebreaker direct assistance required (number, hours, miles)
- Number of convoys with icebreaker escort.

PORT AND LOCK DATA

- Number of ships in port and lock queues every 2 days
- Number of events by port and cargo commodity
- Number of events at each lock
- Average delays at ports and locks.

4. REACH SELECTION

In the simulation, the GL-SLS Navigation System is represented as the series of reaches shown in Figures 4.1 and 4.2, and listed in Tables 4.1 and 4.2 at the end of this section. Also shown in Figures 4.1 and 4.2 are the designated icebreaker commands and designated icebreaker home ports. In describing these reaches, each reach is initially classified as either a port reach, lock reach, or channel reach with boundaries defined as listed in Table 4.2. For port and lock reaches, boundaries were chosen to correspond to the entrance and exit points of the facility, while boundaries for adjacent channel reaches were chosen to correspond to points where trade routes joined, where characteristics of the system changed significantly, or where the U.S. Coast Guard task command boundaries existed.

Once selected, every reach was described by a series of attributes. Port reaches, which were defined as any facility where ships moving over specified trade routes could either load or unload cargo, were described by:

- Maximum Allowable Ship Draft
- Maximum Allowable Ship Length
- Port Turnaround Time

and, for each type of cargo (iron ore, coal, grain, stone, and general cargo), by:

- Stockpile Level
- Number of Docks
- Cargo Arrival (Usage Rate)
- Cargo Loading/Unloading Rate
- Dock Restrictions (Self-Unloaders Only)

where the port turnaround time is the time for a ship to move to and from the docks, excluding time spent in a queue waiting for a dock to become available.

Lock reaches, which were defined as any reach containing a single lock or a system of locks, such as the Welland Canal or St. Lawrence Seaway, were described by the following attributes:

- Ice Conditions
- Maximum Allowable Ship Draft
- Maximum Allowable Ship Length
- Imposed Speed Limit
- Beginning of Daylight Only Navigation

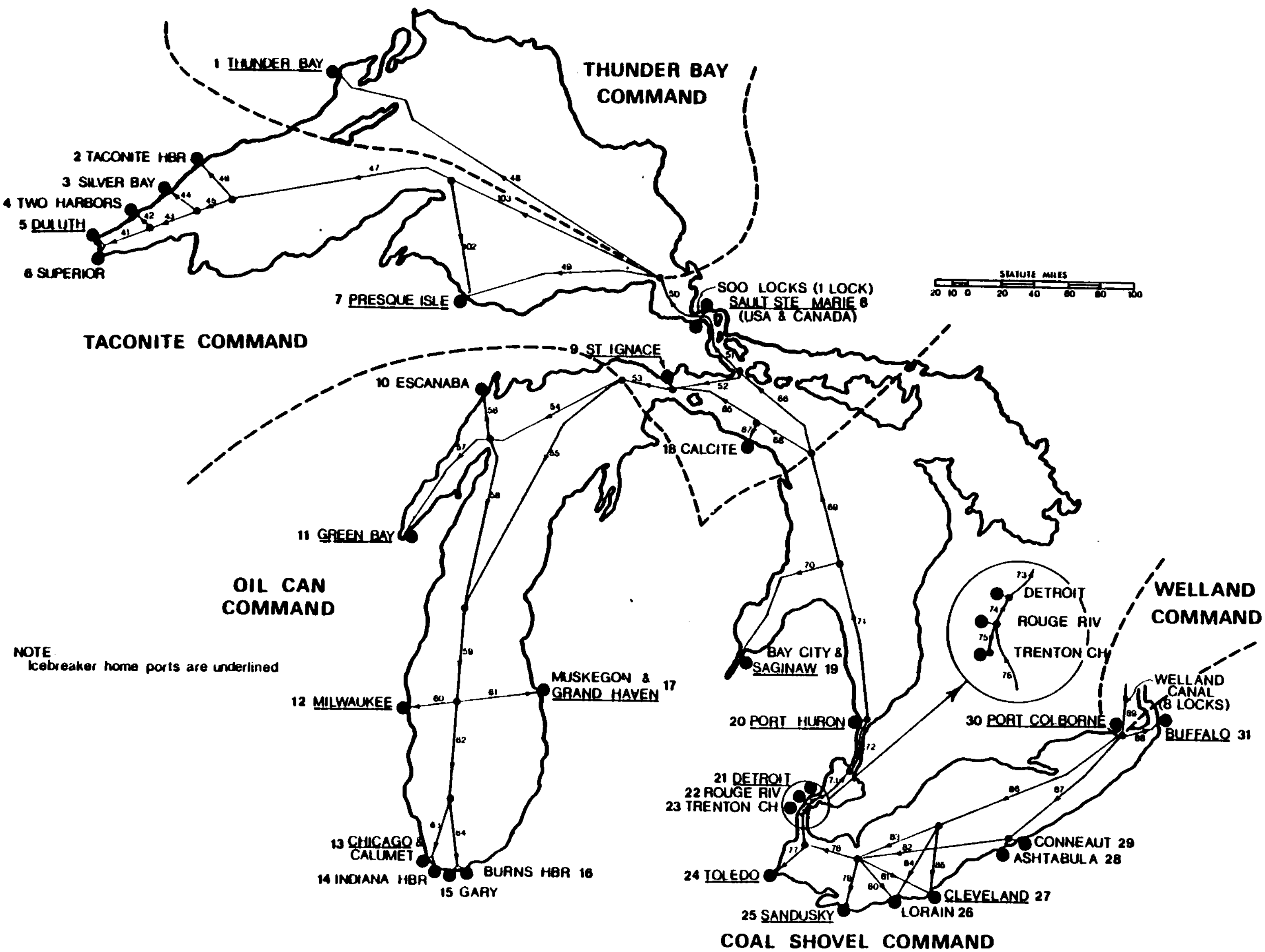

FIGURE 4.1 REACHES COMPRISING THE GL-SLS NAVIGATION SYSTEM

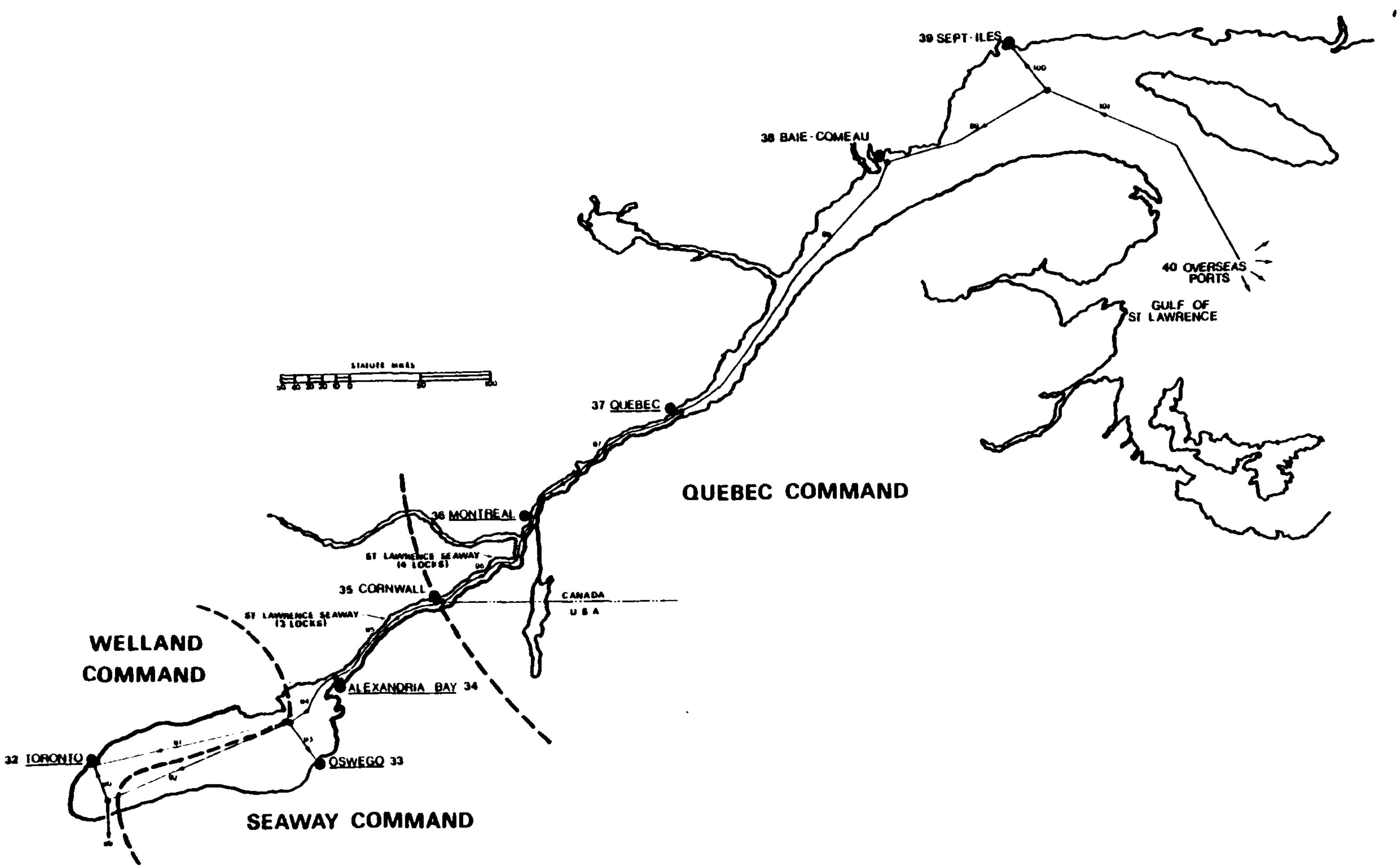

FIGURE 4.2 REACHES COMPRISING THE GL-SLS NAVIGATION SYSTEM

- End of Daylight Only Navigation
- Number of Locks
- Lock Turnback Time

The remaining reaches comprising the lakes and rivers were defined as channel reaches and described by:

- Ice Conditions
- Maximum Allowable Ship Draft
- Maximum Allowable Ship Length
- Imposed Speed Limits
- Beginning of Daylight Only Navigation
- End of Daylight Only Navigation

Ice conditions for every channel and lock reach were defined for each two-week time period in the simulation by dividing each reach into five (5) sections corresponding to the existence of different ice conditions along the length of the reach. Each of these sections, with the exception of the middle one (section 3), was described by a length and the existing level ice thickness, refrozen brash ice thickness, and brash ice thickness. The middle section (section 3) was reserved for open water and only its length was denoted. The elimination of any section was achieved by equating its length to zero. For example, a totally open water reach has the length of section 3 equal to the total length of the reach while the lengths of the other sections equal zero. Similarly, the elimination of any type of ice condition was achieved by setting its respective ice thickness equal to zero. Thus, for example, a reach which contained only brash and refrozen brash ice and did not contain a level ice section has the level ice thickness of all sections set equal to zero. Ice conditions for each reach were prepared for every two week time period for a representative normal and severe winter assuming light, moderate, and heavy ship traffic levels. A more detailed description of the methodology used in defining the ice conditions is presented in Section 3.2 of this report. The values for freezing degree day coefficients (α) and the brash ice porosity (β) for each reach is listed in Table 4.3.

TABLE 4.1

LIST OF PORT REACHES

Port Number	Port Name	Port Number	Port Name
1	*Thunder Bay*	21	*Detroit*
2	Taconite Harbor	22	Rouge River
3	Silver Bay	23	Trenton Ch.
4	Two Harbors	24	*Toledo*
5	*Duluth*	25	*Sandusky*
6	Superior	26	Lorain
7	*Presque Isle*	27	*Cleveland*
8	*Sault Ste. Marie*	28	Ashtabula
9	*St. Ignace*	29	Conneaut
10	*Escanaba*	30	*Port Colborne*
11	*Green Bay*	31	*Buffalo*
12	*Milwaukee*	32	*Toronto*
13	*Chicago* & Calumet	33	*Oswego*
14	Indiana Harbor	34	*Alexandria Bay*
15	Gary	35	Cornwall
16	Burns Harbor	36	*Montreal*
17	Muskegon & *Grand Haven*	37	*Quebec*
18	Calcite	38	Baie-Comeau
19	*Bay City* & Saginaw	39	Sept-Iles
20	*Port Huron*	40	Overseas Ports

NOTE: Icebreaker home ports are in italics.

TABLE 4.2

LIST OF CHANNEL AND LOCK REACHES

REACH	LENGTH (mi)	UPSTREAM NODE N. LAT. - W. LONG.	UPSTREAM NODE LANDMARK	DOWNSTREAM NODE N. LAT. - W. LONG.	DOWNSTREAM NODE LANDMARK
41	29	46°45' - 92°00'	Minnesota Pt.	46°56' - 91°29'	
42	10	47°01' - 91°40'	Two Harbors	46°56' - 91°29'	
43	36	46°56' - 91°29'		47°10' - 90°48'	
44	21	47°17' - 91°16'	Silver Bay	47°10' - 90°48'	
45	16	47°10' - 90°48'		47°17' - 90°31'	
46	25	47°31' - 90°55'	Taconite	47°17' - 90°31'	
47	145	47°17' - 90°31'		47°35' - 87°30'	
48	226	48°26' - 89°12'	Thunder Bay	46°48' - 84°56'	Whitefish Pt.
49	119	46°34' - 87°22'	Presque Isle	46°48' - 84°56'	Whitefish Pt.
50	40	46°48' - 84°56'	Whitefish Pt.	46°30' - 84°21'	Sault Ste. Marie
51	46	46°30' - 84°21'	Sault Ste. Marie	45°57' - 83°54'	DeTour Reef
52	36	45°51' - 84°37'	Round Island	45°57' - 83°54'	DeTour Reef
53	46	45°53' - 85°34'	Lansing Shoal	45°51' - 84°37'	Round Island
54	78	45°24' - 87°00'		45°53' - 85°34'	Lansing Shoal
55	150	44°05' - 87°10'		45°53' - 85°34'	Lansing Shoal
56	24	45°45' - 87°03'	Escanaba	45°24' - 87°00'	
57	80	44°32' - 88°00'	Green Bay	45°24' - 87°00'	
58	93	44°05' - 87°10'		45°24' - 87°00'	
59	55	43°06' - 87°14'		44°05' - 87°10'	
60	32	43°01' - 87°52'	Milwaukee	43°06' - 87°14'	
61	46	43°13' - 86°21'	Muskegon	43°06' - 87°14'	
62	62	42°12' - 87°18'		43°06' - 87°14'	
63	35	41°43' - 87°29'		42°12' - 87°18'	
64	39	41°39' - 87°14'		42°12' - 87°18'	
65	52	45°50' - 84°37'	Round Island	45°33' - 83°39'	
66	68	45°57' - 83°54'	DeTour Reef	45°11' - 83°02'	

TABLE 4.2 (CONTINUED)

REACH	LENGTH (mi)	UPSTREAM NODE N. LAT. - W. LONG.	UPSTREAM NODE LANDMARK	DOWNSTREAM NODE N. LAT. - W. LONG.	DOWNSTREAM NODE LANDMARK
67	11	45°26' - 83°48'	Calcite	45°33' - 83°39'	
68	40	45°33' - 83°39'		45°11' - 83°02'	
69	63	45°11' - 83°02'		44°19' - 82°37'	
70	82	43°39' - 83°51'	Mouth of Saginaw River	44°19' - 82°37'	
71	94	44°19' - 82°37'		43°00' - 82°25'	Port Huron
72	28	43°00' - 82°25'	Port Huron	42°37' - 82°31'	North Channel
73	34	42°37' - 82°31'	North Channel	42°20' - 83°01'	Detroit
74	9	42°20' - 83°01'	Detroit	42°15' - 83°08'	Rouge River
75	7	42°09' - 83°11'	Trenton Ch.	42°15' - 83°08'	Rouge River
76	24	42°15' - 83°08'	Rouge River	41°54' - 83°06'	
77	23	41°42' - 83°28'	Toledo	41°54' - 83°06'	
78	34	41°54' - 83°06'		41°49' - 82°28'	Pelee Passage
79	27	41°28' - 82°42'	Sandusky	41°49' - 82°28'	Pelee Passage
80	25	41°29' - 82°12'	Lorain	41°49' - 82°28'	Pelee Passage
81	40	41°32' - 81°44'	Cleveland	41°49' - 82°28'	Pelee Passage
82	91	41°49' - 82°28'	Pelee Passage	41°59' - 80°42'	
83	52	41°49' - 82°28'	Pelee Passage	42°03' - 81°30'	
84	54	41°29' - 82°12'	Lorain	42°03' - 81°30'	
85	37	41°32' - 81°44'	Cleveland	42°03' - 81°30'	
86	125	42°03' - 81°30'		42°49' - 79°17'	
87	91	41°59' - 80°42'		42°49' - 79°17'	
88	22	42°52' - 78°56'	Buffalo	42°49' - 79°17'	
89	43	42°49' - 79°17'		43°16' - 79°13'	Welland Canal
90	29	43°37' - 49°25'	Toronto	43°16' - 79°13'	Welland Canal
91	134	43°37' - 49°25'	Toronto	43°49' - 76°49'	
92	129	43°16' - 79°13'	Welland	43°49' - 76°49'	
93	29	43°29' - 76°32'	Oswego	43°49' - 76°49'	
94	60	43°49' - 76°49'		44°21' - 75°55'	Alexandria Bay

TABLE 4.2 (CONTINUED)

REACH	LENGTH (mi)	UPSTREAM NODE N. LAT. - W. LONG.	UPSTREAM NODE LANDMARK	DOWNSTREAM NODE N. LAT. - W. LONG.	DOWNSTREAM NODE LANDMARK
95	145	44°21' - 75°55'	Alexandria Bay	45°00' - 74°40'	Cornwall
96	145	45°00' - 74°40'	Cornwall	45°34' - 73°29'	Montreal
97	273	45°34' - 73°29'	Montreal	46°47' - 71°13'	Quebec
98	435	46°47' - 71°13'	Quebec	49°04' - 68°02'	Baie Comeau
99	203	49°04' - 68°02'	Baie Comeau	49°47' - 66°00'	
100	70	50°12' - 66°20'	Sept-Iles	49°47' - 66°00'	
101	406	49°47' - 66°00'		48°18' - 62°16'	To Overseas Ports
102	69	46°34' - 87°22'	Presque Isle	47°35' - 87°30'	
103	131	47°35' - 87°30'		46°48' - 84°56'	Whitefish Pt.

TABLE 4.3

FREEZING DEGREE DAY COEFFICIENTS (α)
AND BRASH ICE POROSITY (β) FOR EACH REACH

NORMAL WINTER						SEVERE WINTER					
REACH	α	β	REACH	α	β	REACH	α	β	REACH	α	β
41	.74	.25	81	.66	.25	41	.68	.25	81	.97	.25
42	.20	.25	82	.82	.25	42	.20	.25	82	.79	.25
43	.20	.25	83	.66	.25	43	.20	.25	83	.97	.25
44	.20	.25	84	.66	.25	44	.20	.25	84	.97	.25
45	.20	.25	85	.87	.25	45	.20	.25	85	.79	.25
46	.20	.25	86	.82	.25	46	.20	.25	86	.84	.25
47	.20	.25	87	.82	.25	47	.20	.25	87	.84	.25
48	.95	.25	88	.82	.25	48	.80	.25	88	.84	.25
49	.68	.25	89	.84	.25	49	.57	.25	89	.84	.25
50	.48	.25	90	.84	.25	50	.44	.25	90	.84	.25
51	.53	.25	91	.84	.25	51	.59	.25	91	.84	.25
52	.53	.25	92	.84	.25	52	.52	.25	92	.84	.25
53	.52	.25	93	1.27	.25	53	.51	.25	93	.84	.25
54	1.07	.25	94	.58	.25	54	.65	.25	94	1.16	.25
55	1.28	.25	95	.61	.25	55	.65	.25	95	.61	.25
56	.75	.25	96	.63	.25	56	.64	.25	96	.63	.25
57	.60	.25	97	.63	.25	57	.67	.25	97	.63	.25
58	1.17	.25	98	.63	.25	58	.52	.25	98	.63	.25
59	.86	.25	99	.63	.25	59	.61	.25	99	.63	.25
60	.43	.25	100	.63	.25	60	.61	.25	100	.63	.25
61	.57	.25	101	.63	.25	61	.66	.25	101	.63	.25
62	.52	.25	102	.77	.25	62	.65	.25	102	.57	.25
63	.47	.25	103	.62	.25	63	.66	.25	103	.57	.25
64	.62	.25				64	.66	.25			
65	.48	.25				65	.51	.25			
66	.70	.25				66	.64	.25			
67	1.16	.25				67	.57	.25			
68	.90	.25				68	.64	.25			
69	.90	.25				69	1.88	.25			
70	.84	.25				70	1.18	.25			
71	.78	.25				71	.70	.25			
72	.75	.25				72	.70	.25			
73	.72	.25				73	.68	.25			
74	1.11	.25				74	.70	.25			
75	1.11	.25				75	.70	.25			
76	.72	.25				76	.68	.25			
77	.65	.25				77	.78	.25			
78	.65	.25				78	.78	.25			
79	.66	.25				79	.82	.25			
80	.57	.25				80	.94	.25			

5. ICEBREAKER AND SHIP CLASS SELECTION

In the simulation, ships which transit the GL/SLS Navigation System were divided into four major types:

- Laker Bulk Vessels
- Ocean-Going Bulk Vessels
- Ocean-Going General Cargo Vessels
- Icebreakers

These major vessel types, with the exception of icebreakers, were further divided into classes to distinguish between different vessel sizes, carrying capacities, and characteristics using the following standard Corps of Engineers Classification based on ship length:

CORPS OF ENGINEERS VESSEL CLASSIFICATION BY LENGTH

Class	Vessel Length (feet)
1	Under 400
2	400 - 499
3	500 - 549
4	550 - 599
5	600 - 649
6	650 - 699
7	700 - 730
8	731 - 849
9	850 - 949
10	950 - 1000

For icebreakers, three (3) vessel classes were used corresponding to the U.S. Coast Guard's classification of Class B, C, and D icebreakers. Each vessel type and class, other than icebreakers, used in the simulation to represent the vessels operating in the extended navigation season are described in Tables 5.1, 5.2, and 5.3 by the following characteristics listed below. In a similar manner, each icebreaker class is described by the series of characteristics in Table 5.4.

Characteristic	Description
Length	Overall length of ship (feet).
Beam	Maximum width of ship at the waterline (feet).
Horsepower	Maximum shaft horsepower generated by engines (hp).
Engine Type	Type of propulsion system.

TABLE 5.1

LAKER BULK VESSEL CHARACTERISTICS

CHARACTERISTICS	SHIP CLASS				
	5	6	7	8	10
Length (feet)	640	699	730	767	1,000
Beam (feet)	67	70	75	70	105
Horsepower	4,000	7,700	8,800	7,000	14,000
Engine Type	Steam Turbine	Steam Turbine	Steam Turbine	Steam Turbine	Diesel
V_{design}	14.5	16.5	16.5	16.5	18.0
Locking Time SLS (minutes)	37	39	41	41	59
Locking Time WELLAND (minutes)	36	37	39	40	43
Locking Time SOO (minutes)	56	57	55	66	87
Midsummer Draft (feet)	24.6	26.3	27.9	26.2	28.6
Winter Draft (feet)	22.0	24.5	26.0	24.5	28.6
Long Tons/Foot Immersion	996	1,206	1,452	1,404	2,542
Self-Unloading Rate (long tons/hr.)	3,000	4,000	5,000	5,000	8,500
MS Iron Ore (long tons)	18,150	22,400	27,600	26,500	57,500
MS Coal (long tons)	16,340	20,160	24,840	23,850	51,750
MS Grain (long tons)	16,340	20,160	24,840	23,850	51,750
Ice Class	II	IC	II	II	IC
Number of Crew	27	32	32	38	21
Total Sale Price (10^6)	6.97	12.15	17.29	17.28	33.60
Cubic Number	15,526	18,817	21,710	22,008	50,946
Gross Registered Tons	10,291	10,317	13,390	15,483	24,199
Capital Recovery Factor	0.157	0.139	0.134	0.139	0.131
Horsepower/Length Ratio	6.25	11.02	12.05	9.13	14.00

TABLE 5.2

OCEAN-GOING BULK VESSEL CHARACTERISTICS

CHARACTERISTICS	SHIP CLASS 4	5	6	7
Length (feet)	566	635	681	709
Beam (feet)	72	75	75	75
Horsepower	9,000	9,600	11,500	12,800
Engine Type	Diesel	Diesel	Diesel	Diesel
V_{design}	19.0	17.3	18.4	17.3
Locking Time SLS (minutes)	33	37	39	41
Locking Time WELLAND (minutes)	35	36	37	39
Locking Time SOO (minutes)	56	56	57	55
Midsummer Draft (feet)	31.0	33.4	35.1	36.0
Winter Draft (feet)	31.0	33.4	35.1	36.0
Long Tons/Foot Immersion	1,125	901	1,266	1,290
MS Grain (long tons)	16,257	19,698	21,870	32,105
Ice Class	IB	IC	IC	IB
Number of Crew	30	30	30	30
Total Sale Price (10^6)	2.38	7.20	10.27	11.31
Cubic Number	13,510	17,148	19,312	20,671
Gross Registered Tonnage	14,468	12,100	19,644	21,288
Capital Recovery Factor	0.33	0.20	0.17	0.17

TABLE 5.3

OCEAN-GOING GENERAL CARGO CHARACTERISTICS

CHARACTERISTICS	SHIP CLASS 1	SHIP CLASS 2	SHIP CLASS 3
Length (feet)	397	477	528
Beam (feet)	55	64	75
Horsepower	5,400	10,000	18,400
Engine Type	Diesel	Diesel	Diesel
V_{design} (mph)	18.4	19.6	23.6
Locking Time SLS (minutes)	30	31	32
Locking Time WELLAND (minutes)	31	32	34
Locking Time SOO (minutes)	42	48	54
Midsummer Draft (feet)	25.3	28.6	31.5
Winter Draft (feet)	25.3	28.6	31.5
Long Tons/Foot Immersion	420	720	662
MS General (long tons)	5,313	10,863	10,226
Ice Class	IA	IA	IA
Number of Crew	30	30	30
Total Sale Price (10^6)	5.310	5.525	8.670
Cubic Number	5,523	8,908	12,473
Gross Registered Tons	5,419	9,003	10,846
Capital Recovery Factor	0.17	0.17	0.16

TABLE 5.4

ICEBREAKER CHARACTERISTICS

Characteristics	Class B	Class C	Class D
Length (feet)	280	130	107
Beam (feet)	70	34	25
Horsepower	10,000	2,500	1,000
V_{design} (mph)	19.2	17.1	14.7
Maximum Number of Ships in Convoy	6	3	--
Maximum Endurance for Convoy (hr)	∞	36	--

CHARACTERISTIC - Cont.	DESCRIPTION - Cont.
V_{design}	Maximum speed capability of the ship in open water (mph)
Locking Time - SLS	Time required for ship to lock through one lock at the St. Lawrence Seaway excluding delays (minutes)
Locking Time - WELLAND	Time required for ship to lock through one lock at the Welland Canal excluding delays (minutes)
Locking Time - SOO	Time required for ship to lock through a lock at Sault Ste. Marie excluding delays (minutes)
Midsummer Draft	Draft to which a vessel can load amid-ships during the designated Midsummer Season (feet)
Winter Draft	Draft to which a vessel can load amid-ships during the designated Winter Season (feet)
Long Tons/Foot Immersion	Long tons required to increase draft of vessel one foot (long tons per foot)
Self-Unloading Rate	Rate at which cargo can be unloaded by on-board unloading devices (long tons per hour)
MS Iron Ore	Maximum iron ore capacity required to achieve Midsummer Draft (long tons)
MS Coal	Maximum coal capacity (long tons) at Midsummer Draft
MS Grain	Maximum grain capacity (long tons) at Midsummer Draft
MS General Cargo	Maximum general cargo capacity at Midsummer Draft (long tons)

CHARACTERISTIC - Cont.	DESCRIPTION - Cont.
Ice Class	Rating as to the ice condition the ship can proceed through: IA: Extremely severe ice conditions IB: Severe ice conditions IC: Mild ice conditions II: Light ice conditions
Number of Crew	Number of working personnel aboard vessel
Total Sale Price	Estimated current sale price of vessel
Cubic Number	Product of the vessel's length, beam and depth divided by 100 (ft^3)
Gross Registered Tonnage	Cubic feet of interior space divided by 100
Capital Recovery Factor	Factor by which the initial investment is multiplied in order to find the annual cost of capital recovery

These vessel characteristics were obtained by selecting representative ships for each class and gathering data for each from *Greenwood's Guide to Great Lakes Shipping* [9] and from discussions with owners. Once the data was gathered, certain characteristics were adjusted to more accurately reflect ships operating in specific trades. For example, lakers operating in the grain and coal trade generally have deeper cargo compartments than the usual iron ore ship because of the lower cargo density (lbs per cubic foot) of grain and coal compared to iron ore. These ships thus require more cubic volume capacity per ton of grain or coal than per ton of iron ore. To reflect this condition, the maximum grain and coal capacities indicated for laker bulk vessels were defined as 90% of the maximum iron ore capacities.

In discussing individual ship classes, an important measure of performance is their ice transiting capability or icebreaking performance. Numerous measures of icebreaking performance have been proposed in the past. Two of the more frequently encountered measures are thickness of sheet ice which can be broken in either a continuous or ramming mode of operation, and penetration distance after impact during ramming. These measures are not very meaningful in terms of cargo ships whose primary purpose is to move cargo from one point to another and not to break ice per se. Therefore, a much more meaningful measure of icebreaking or ice navigability is the speed a ship can attain through a given ice field. In Figures 5.1 through 5.5 the maximum speed of advance versus brash ice thickness for various refrozen brash ice thicknesses is given for representative ship classes. The method used in producing these figures is described in Section 3.3 of this report.

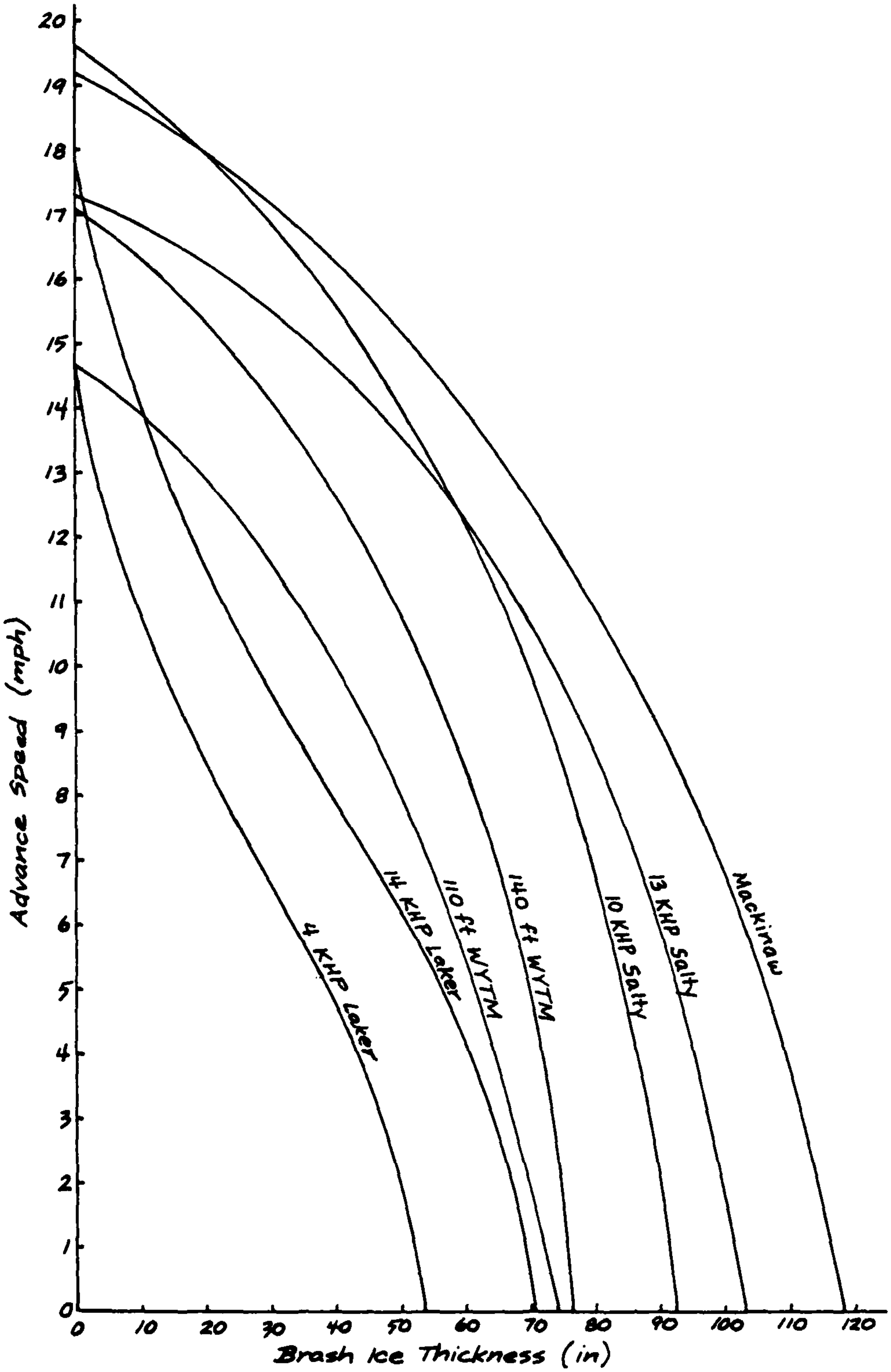

FIGURE 5.1 SPEED OF ADVANCE VS UNCONSOLIDATED BRASH ICE THICKNESS (0 inches Refrozen Brash Ice)

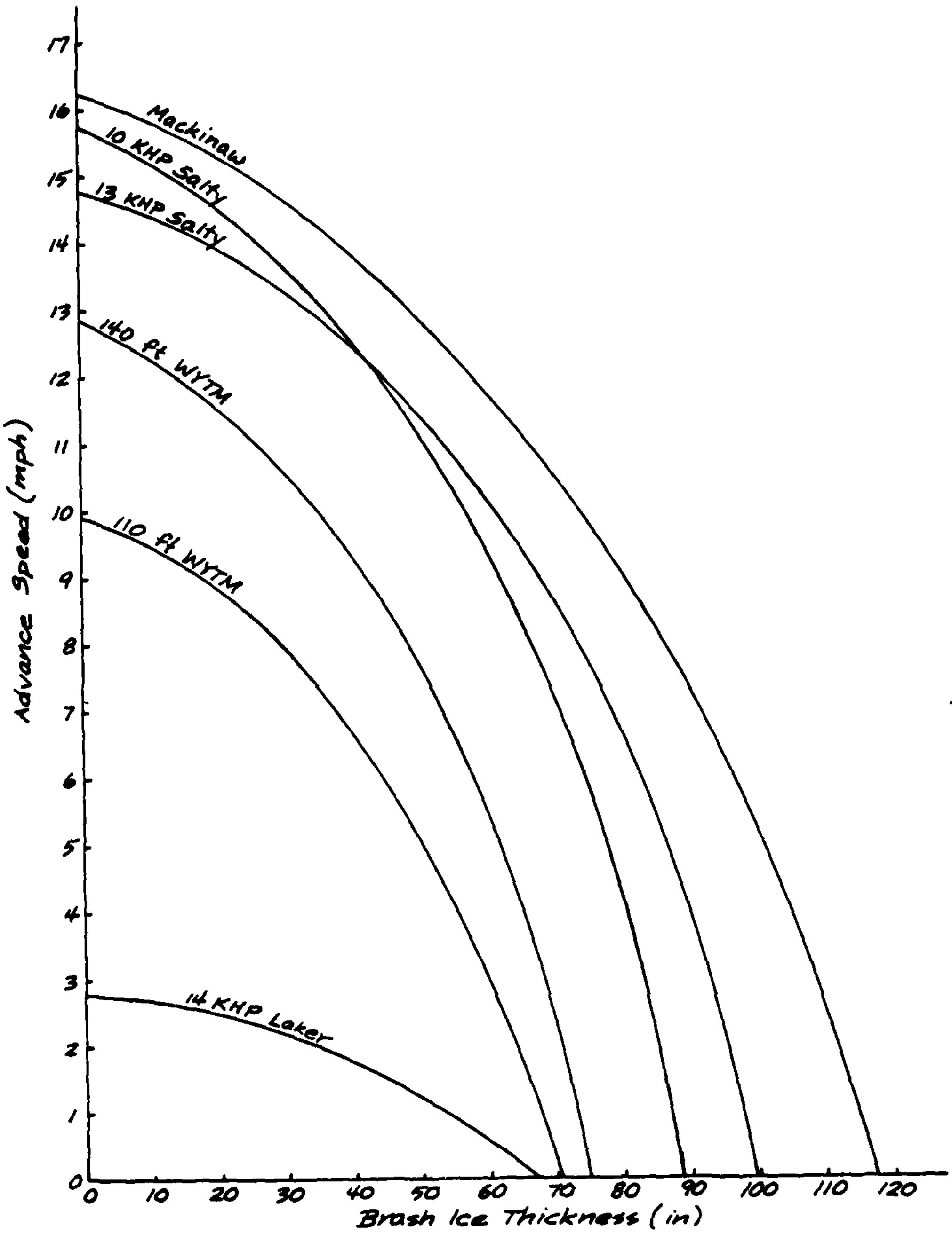

FIGURE 5.2 SPEED OF ADVANCE VS UNCONSOLIDATED BRASH ICE THICKNESS (5 inches Refrozen Brash Ice)

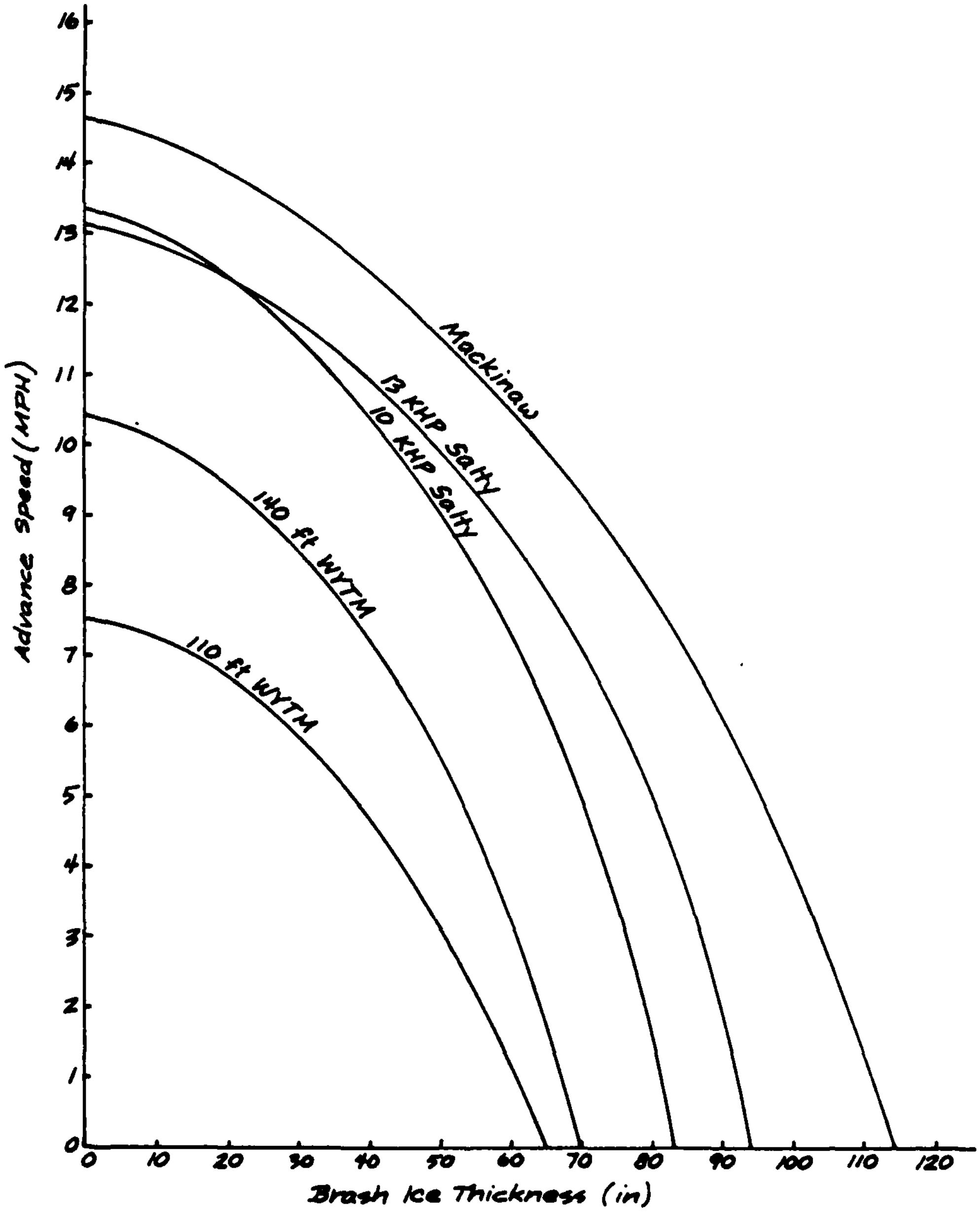

FIGURE 5.3 SPEED OF ADVANCE VS UNCONSOLIDATED BRASH ICE THICKNESS (10 inches Refrozen Brash Ice)

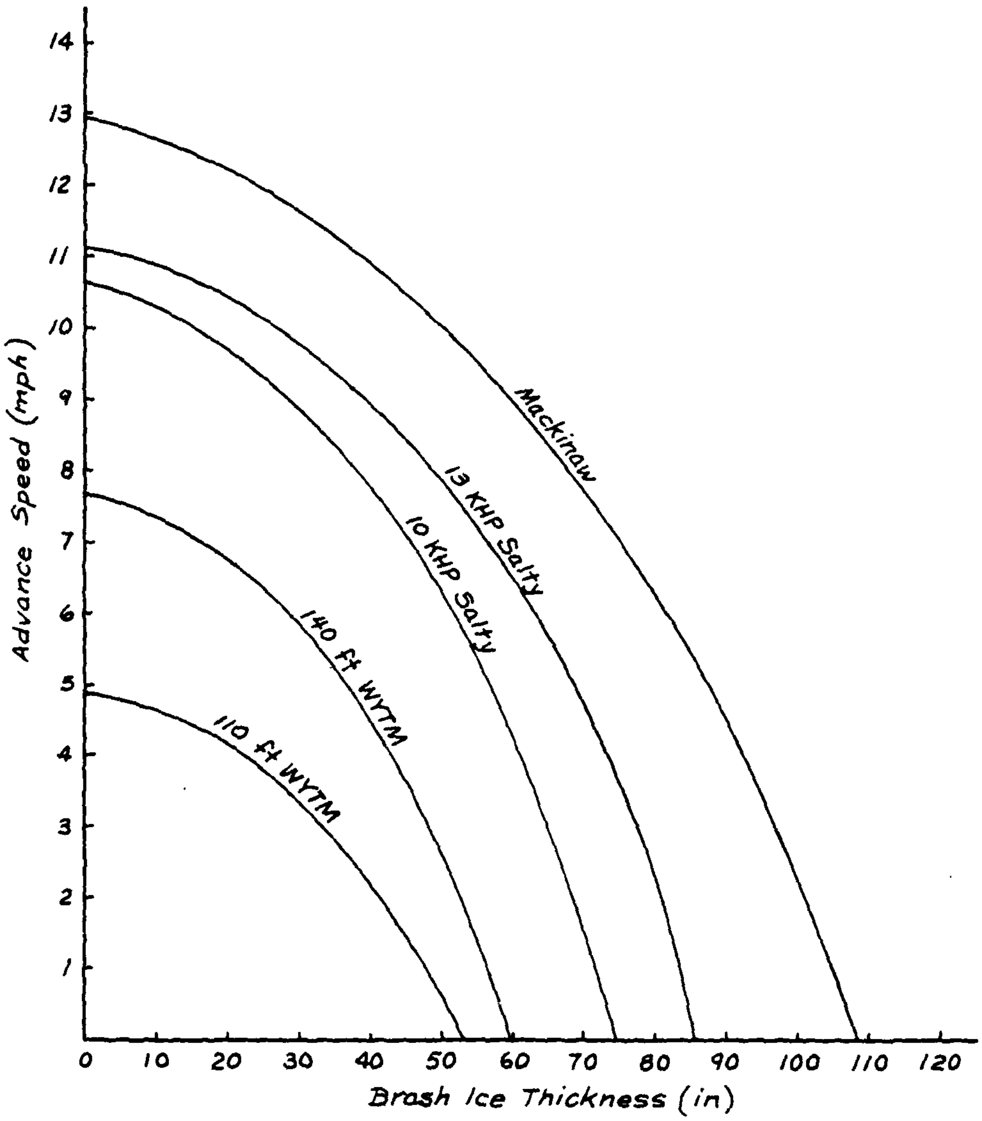

FIGURE 5.4 SPEED OF ADVANCE VS UNCONSOLIDATED BRASH ICE THICKNESS (15 inches Refrozen Brash Ice)

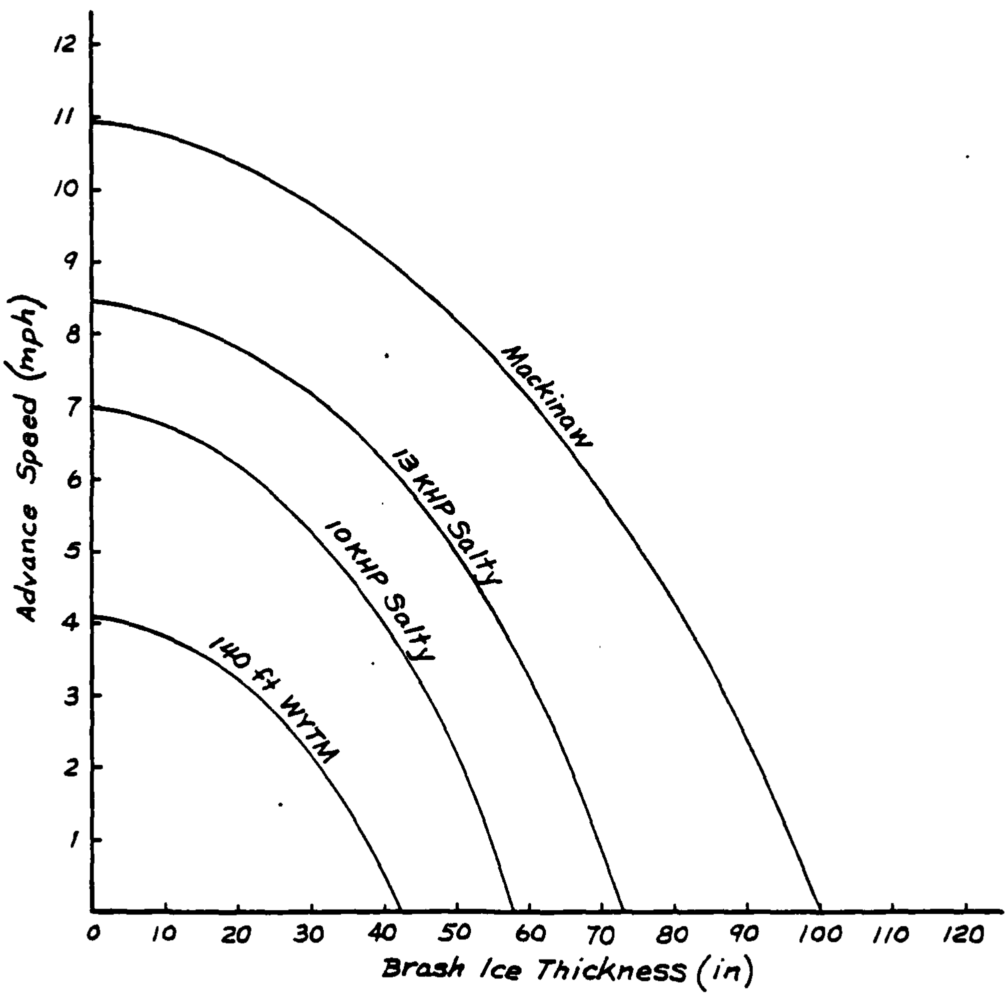

FIGURE 5.5 SPEED OF ADVANCE VS UNCONSOLIDATED BRASH ICE THICKNESS (20 inches Refrozen Brash Ice)

6. RESULTS OF SIMULATION RUNS

6.1 Overview

In the following subsections, the results of the validation and production runs are presented and discussed. The validation of the simulation, which is presented in Section 6.2, consisted of three (3) separate phases: (1) Series of step-by-step planned debugging procedures; (2) Comparison of 1975-76 "normal" winter with historical USCG icebreaker statistics; and, (3) Comparison of 1975-76 fixed icebreaker fleet statistics with icebreaker statistics generated by maximum response time mode. The production runs listed in Section 6.3 consisted of ten (10) executions of the simulation with input data varied to assess the following:

- Effect of a 20% increase in cargo tonnage with a fixed fleet of icebreakers (normal winter).

- Effect of a 12-hour variation in maximum response time on icebreaker requirements (normal winter).

- Effect of convoys on icebreaker requirements (normal winter).

- Comparison of the maximum response time (MRT) generated icebreaker fleet to the USCG estimated fleet (normal winter).

- Effect of winter severity (normal vs severe) on icebreaker requirements.

- Effect of having only Class B icebreakers escort convoys, as opposed to both Class B and Class C, on icebreaker requirements (severe winter).

- Effect of prohibiting vessels with low SHP from operating in the extended season on icebreaker requirements (severe winter).

- Effect of conducting channel clearing in certain channels on icebreaker requirements (severe winter).

- Comparison of the maximum response time (MRT) generated icebreaker fleet to the USCG estimated fleet (severe winter).

A comparison of the results assessing the above items is presented in Section 6.3. Detailed summaries of the results of the ten production runs are summarized in tabular form in Section 6.4.

6.2 Validation

There were three phases to the validation process:

- PHASE 1 - Detailed simulation module checkout
- PHASE 2 - Fixed icebreaker fleet run using historic 1975-76 data
- PHASE 3 - Maximum response time run to compare with Phase 2

6.2.1 Phase 1 of the Validation - Checkout of Simulation Modules

Input Data to Ship Processing Model

The two most important aspects of the simulation are the ice conditions and the maximum speed capability of the commercial vessels, since these translate directly into icebreaker support requirements. Figures 5.1 through 5.5 illustrate the maximum speed of advance versus ice type and thickness for various vessel classes. From these plots, the performance in ice of each ship class can easily be established. For example, a Class 5 Laker can proceed through approximately 40 inches of brash ice with zero refrozen thickness at a speed of advance of 5 mph, but it will become stuck in 50 inches of brash ice assuming a vessel speed of less than 2 mph corresponds to a vessel being stuck. For a Class 10 Laker, the maximum brash ice thickness it can proceed through is 69 inches with zero refrozen thickness, and 33 inches of brash with a 5 inch refrozen cover. These curves, particularly the maximum ice thickness at 2 mph, appear to be reasonable and consistent with experience.

The ice conditions data files were reviewed reach-by-reach to ensure that the predicted occurrences of ships becoming stuck and the trouble areas identified were also consistent with operating experience. The input data files for normal and severe winters contained ice growth calibration factors by reach, which were adjusted to obtain realistic ice conditions. For example, it is well known that brash ice accumulates to greater depths in the confined river channels than it does in the open lakes. Since the same equations and temperatures are used for both in the Ice Growth Model, these calibration factors provided the necessary differentiation in brash ice buildup. In Tables 6.1 through 6.4, the final results of this analysis are presented showing what class vessels will be stuck where, and when, for the laker fleet. These tables agree with operating experience in identifying the trouble areas as a function of winter severity and traffic level. By using the reach calibration factors, environmental aspects not directly accounted for in the Ice Growth Model, such as the effect of winds, currents, and channel widths, were included.

TABLE 6.1

OCCURRENCES OF LAKERS BECOMING STUCK FOR SEVERE WINTER AND HEAVY TRAFFIC

CLASS 5

Reach Number	Period 2	3	4	5	6	7	8	9	10
41			X	X	X	X	X	X	X
42									
43									
44									
45									
46									
47									
48			X	X	X	X	X	X	X
49					X	X			
50				X	X	X	X	X	X
51			X	X	X	X	X	X	X
52						X	X	X	X
53				X	X	X	X	X	X
54						X		X	
55									
56			X	X	X	X	X	X	
57			X	X	X	X	X	X	
58									
59									
60									
61									
62									
63									
64									
65						X		X	X
66									
67									
68									
69				X					
70			X	X	X	X	X		
71									
72				X	X	X			
73				X	X				
74									
75									
76				X	X	X			
77				X	X	X			
78				X	X	X			
79				X	X	X			
80				X	X	X			
81				X	X	X			
82				X	X	X			
83				X	X	X			
84				X	X	X			
85				X	X	X			
86				X	X	X	X		
87				X	X	X	X		
88			X	X	X	X	X	X	X
89				X	X	X	X		
90									
91									
92									
93									
94			X	X	X	X	X		
95			X	X	X	X	X		
96			X	X	X	X	X	X	
97			X	X	X	X	X		
98			X	X	X	X			
99				X	X	X	X		
100				X	X	X	X		
101					X	X	X		
102						X			
103						X			

CLASS 6

Reach Number	Period 2	3	4	5	6	7	8	9	10
41				X	X	X	X	X	X
42									
43									
44									
45									
46									
47									
48					X	X	X		
49									
50									X
51					X	X	X	X	X
52									
53						X	X	X	X
54									
55									
56				X	X	X	X		
57				X	X	X	X		
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70			X	X	X	X	X		
71									
72									
73									
74									
75									
76						X			
77					X				
78					X				
79									
80					X				
81					X				
82									
83					X				
84					X				
85									
86					X	X			
87					X	X			
88			X	X	X	X	X	X	
89					X	X			
90									
91									
92									
93									
94				X	X	X			
95				X	X	X	X		
96				X	X	X	X	X	
97				X	X	X	X		
98					X	X			
99						X	X		
100						X	X		
101									
102									
103									

CLASS 7

Reach Number	Period 2	3	4	5	6	7	8	9	10
41				X	X	X	X	X	X
42									
43									
44									
45									
46									
47									
48					X	X	X		
49									
50									
51						X	X	X	X
52									
53						X		X	X
54									
55									
56					X	X			
57				X	X	X	X		
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70				X	X	X	X		
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86						X			
87						X			
88				X	X	X	X	X	
89					X	X			
90									
91									
92									
93									
94					X	X			
95					X	X	X		
96				X	X	X	X	X	
97				X	X	X	X		
98					X	X			
99						X	X		
100						X	X		
101									
102									
103									

CLASS 8

Reach Number	Period 2	3	4	5	6	7	8	9	10
41			X	X	X	X	X	X	X
42									
43									
44									
45									
46									
47									
48				X	X	X	X	X	
49									
50							X	X	X
51					X	X	X	X	X
52									
53					X	X	X	X	X
54									
55									
56				X	X	X	X		
57				X	X	X	X	X	
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70			X	X	X	X	X		
71									
72									
73									
74									
75									
76						X			
77					X				
78					X				
79					X				
80					X				
81					X				
82									
83					X				
84					X				
85									
86					X	X			
87					X	X			
88			X	X	X	X	X	X	
89				X	X	X	X		
90									
91									
92									
93									
94				X	X	X			
95				X	X	X	X		
96				X	X	X	X	X	
97				X	X	X	X		
98				X	X	X			
99					X	X	X		
100					X	X	X		
101									
102									
103									

CLASS 10

Reach Number	Period 2	3	4	5	6	7	8	9	10
41				X	X	X	X	X	X
42									
43									
44									
45									
46									
47									
48					X	X	X		
49									
50									
51						X	X	X	X
52									
53								X	X
54									
55									
56					X	X			
57				X	X	X	X		
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70				X	X	X	X		
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86						X			
87						X			
88				X	X	X	X		
89					X	X			
90									
91									
92									
93									
94					X	X			
95					X	X	X		
96					X	X	X	X	
97					X	X	X		
98					X	X			
99									
100									
101									
102									
103									

TABLE 6.2

OCCURRENCES OF LAKERS BECOMING STUCK FOR SEVERE WINTER AND MODERATE TRAFFIC

Reach Number	CLASS 5									CLASS 6									CLASS 7									CLASS 8									CLASS 10								
	Period									Period									Period									Period									Period								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
41	X	X	X	X	X	X	X	X	X					X	X			X						X							X	X	X	X	X	X						X			
42																																													
43																																													
44																																													
45																																													
46																																													
47																																													
48		X	X	X	X	X									X																		X												
49						X																																							
50				X	X	X	X	X	X																																				
51		X	X	X	X	X	X	X	X																								X		X	X									
52			X			X																																							
53			X	X	X	X	X	X	X																																				
54			X	X		X																																							
55			X	X																																									
56		X	X	X	X	X																											X												
57		X	X	X	X	X	X							X	X								X	X							X	X	X									X			
58																																													
59																																													
60			X																																										
61			X																																										
62																																													
63			X																																										
64			X																																										
65						X																																							
66			X	X																																									
67		X	X																																										
68			X	X																																									
69				X									X									X									X									X					
70		X	X	X	X	X	X						X	X	X							X	X	X						X	X	X	X							X	X	X			
71				X																																									
72			X	X	X	X																																							
73			X	X	X	X																																							
74			X																																										
75			X																																										
76			X	X	X	X																																							
77		X	X	X	X	X																																							
78		X	X	X	X	X																																							
79		X	X	X	X	X																																							
80		X	X	X	X	X																																							
81		X	X	X	X	X																																							
82		X	X	X	X																																								
83		X	X	X	X	X																																							
84		X	X	X	X	X																																							
85		X	X	X	X																																								
86		X	X	X	X	X																																							
87		X	X	X	X	X																																							
88		X	X	X	X	X	X						X	X	X	X						X	X	X							X	X	X	X						X	X	X			
89		X	X	X	X	X									X																		X												
90																																													
91																																													
92																																													
93																																													
94		X	X	X	X	X																									X	X	X												
95			X	X	X	X	X								X									X								X	X												
96		X	X	X	X	X	X	X						X	X									X								X	X									X			
97		X	X	X	X	X	X							X	X									X								X	X									X			
98	X	X	X	X	X	X									X																	X	X												
99		X	X	X	X	X	X																																						
100		X	X	X	X	X	X																																						
101		X	X	X	X	X																																							
102																																													
103																																													

TABLE 6.3

OCCURRENCES OF LAKERS BECOMING STUCK FOR NORMAL WINTER AND HEAVY TRAFFIC

Reach Number	CLASS 5 Period								
	2	3	4	5	6	7	8	9	10
41			X	X	X	X	X	X	
42									
43									
44									
45									
46									
47									
48				X	X	X	X	X	
49							X		
50					X	X	X	X	X
51				X	X	X	X	X	X
52									
53					X	X	X	X	
54					X	X	X		
55					X		X		
56					X		X	X	
57				X	X	X	X	X	
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70									
71									
72									
73									
74									
75									
76				X	X				
77				X	X				
78				X	X				
79									
80									
81									
82									
83									
84									
85									
86				X	X				
87				X	X				
88				X	X	X			
89									
90									
91									
92									
93									
94									
95					X	X	X		
96					X	X	X		
97			X	X	X	X	X	X	
98			X	X	X	X	X	X	
99				X	X	X	X	X	
100				X	X	X	X	X	
101					X	X	X	X	
102									
103									

Reach Number	CLASS 6 Period								
	2	3	4	5	6	7	8	9	10
41				X	X	X	X	X	
42									
43									
44									
45									
46									
47									
48					X	X	X	X	
49									
50								X	
51							X	X	
52									
53							X	X	
54							X		
55									
56									
57									
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70									
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86									
87									
88					X				
89									
90									
91									
92									
93									
94									
95									
96									
97				X	X	X	X	X	
98					X	X	X	X	
99					X	X	X	X	
100					X	X	X	X	
101									
102									
103									

Reach Number	CLASS 7 Period								
	2	3	4	5	6	7	8	9	10
41				X	X	X	X	X	
42									
43									
44									
45									
46									
47									
48					X	X	X	X	
49									
50									
51									
52									
53									
54							X		
55									
56									
57									
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70									
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86									
87									
88					X				
89									
90									
91									
92									
93									
94									
95									
96									
97				X	X	X	X	X	
98					X	X	X	X	
99						X	X	X	
100						X	X	X	
101									
102									
103									

Reach Number	CLASS 8 Period								
	2	3	4	5	6	7	8	9	10
41				X	X	X	X	X	
42									
43									
44									
45									
46									
47									
48					X	X	X	X	
49									
50							X	X	
51							X	X	
52									
53							X	X	
54							X		
55									
56									
57									
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70									
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86									
87									
88				X	X				
89									
90									
91									
92									
93									
94									
95							X		
96							X		
97				X	X	X	X	X	
98				X	X	X	X	X	
99					X	X	X	X	
100					X	X	X	X	
101							X	X	
102									
103									

Reach Number	CLASS 10 Period								
	2	3	4	5	6	7	8	9	10
41				X	X	X	X	X	
42									
43									
44									
45									
46									
47									
48							X	X	
49									
50									
51									
52									
53									
54							X		
55									
56									
57									
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70									
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86									
87									
88					X				
89									
90									
91									
92									
93									
94									
95									
96									
97				X	X	X	X	X	
98					X	X	X	X	
99						X	X	X	
100						X	X	X	
101									
102									
103									

TABLE 6.4

OCCURRENCES OF LAKERS BECOMING STUCK FOR NORMAL WINTER AND MODERATE TRAFFIC

	CLASS 5									CLASS 6									CLASS 7									CLASS 8									CLASS 10								
Reach Number	Period									Period									Period									Period									Period								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
41	X	X	X	X	X	X	X	X						X	X	X	X						X		X	X					X	X	X	X	X								X	X	
42																																													
43																																													
44																																													
45																																													
46																																													
47																																													
48			X	X	X	X	X	X								X																		X											
49			X				X																																						
50					X	X	X	X																																					
51				X	X	X	X	X																														X								
52																																													
53						X	X	X																																					
54				X	X	X	X																											X											
55				X	X		X																																						
56			X	X	X		X																																						
57			X	X	X		X																																						
58				X			X																																						
59																																													
60																																													
61																																													
62																																													
63																																													
64																																													
65																																													
66			X																																										
67							X																																						
68																																													
69																																													
70																																													
71																																													
72																																													
73																																													
74				X																																									
75				X																																									
76				X																																									
77				X	X																																								
78				X	X																																								
79																																													
80																																													
81																																													
82			X																																										
83																																													
84																																													
85			X																																										
86			X	X	X																																								
87			X	X	X																																								
88			X	X	X																																								
89			X	X																																									
90																																													
91																																													
92																																													
93				X																																									
94																																													
95			X	X	X	X	X																																						
96			X	X	X	X	X																																						
97			X	X	X	X	X	X						X	X	X	X								X	X						X	X	X	X								X	X	
98	X	X	X	X	X	X	X	X							X	X	X								X	X						X	X	X	X								X	X	
99	X	X	X	X	X	X	X	X								X	X																	X	X										
100		X	X	X	X	X	X	X								X	X																	X	X										
101		X	X	X	X	X	X	X																																					
102				X																																									
103																																													

Specific problem areas, which were identified and modeled in the simulation, are:

Duluth, Minnesota/Superior, Wisconsin - Some of the coldest air temperatures on the Great Lakes occur here because predominantly northwest winds reach the water only after passing over large expanses of land. The Apostle Islands east of the harbor entrance prevent ice from moving into open Lake Superior and occasional easterly winds may actually cause an ice jam at the harbor entrance. Currently there is no year-round shipping because of the ice conditions, while only a few miles to the northeast, Two Harbors does not experience blockage by ice.

Whitefish Bay, Lake Superior - This small area at the southeast corner of the lake is the first part of Lake Superior to experience problems. Ice accumulations occur here due to wind-driven ice from Lake Superior being trapped within the confines of the bay.

St. Marys River, Michigan - Heavy shipping in this shallow, narrow channel causes brash ice buildups, particularly just downstream of Sault Ste. Marie in Little Rapids Cut and Lake Nicolet. Some of the problems are due to ice moving with the current being trapped in narrow sections. Increased future traffic should be expected to bring more water to the surface, thus causing thicker brash accumulations.

Straits of Mackinac, Michigan - Wind-driven ice from Lake Michigan accumulates between St. Ignace and Lansing Shoal due to the constriction at this point.

Detroit/St. Clair System and Western Lake Erie - Shallow water leads to a low thermal inertia in the area so that ice forms here early in the season. Islands in the lake stabilize the ice cover, minimize waves, and thus prevent wind from moving the ice away from the western shore. Ice floes from Lake Huron pass through the St. Clair River, but stop in Lake St. Clair and the upper Detroit River, causing problems for shipping.

Buffalo, New York - The situation at Buffalo is similar in origin to that in Whitefish Bay, but much worse due to the shallow water in Lake Erie. Predominantly west winds concentrate all the ice formed on Lake Erie into heavily rafted windrows at the harbor entrance at the far eastern end of Lake Erie.

Welland Canal, Ontario - Although no winter shipping takes place now, heavy winter traffic would cause problems here similar to those in the St. Marys River.

St. Lawrence Seaway - The situation here is similar to that of the Welland Canal and St. Marys River. Brash buildups will occur in the shallow channels.

Lower St. Lawrence River, Quebec - Cold temperatures here cause a heavy ice growth.

Execution of Ship Processing Model

As part of the module checkout, a new or modified code in the Ship Processing Model was "computed" by hand by a debugging team to check the logic and mathematics of each subroutine. Then, special debugging input speed files were prepared such that each ship or icebreaker class traveled at 10 mph in every reach. A very detailed printout during the program execution was examined while a prepared sequence of runs for the Ship Processing Model was followed to exercise the model in a progressively more elaborate execution:

- Fixed icebreaker fleet mode; small commercial fleet; convoy flags off. Five runs to check stuck codes 1, 2, 3, 4, 5 (stuck at upper end of reach due to resistance, stuck at upper end of reach in a turn, stuck at lower end of reach due to resistance, stuck at lower end of reach in a turn, stuck at either end of the reach) in reach 103.

- Five runs, same as above, but stuck in reaches 103, 59, 47, 97.

- One run, with stuck code 1 in reach 103, 2 in reach 59, 3 in reach 47, 4 in reach 86, 5 in reach 97.

- One run with no ships stuck, but convoy in reaches 50-51.

- Same as preceding step, but also with convoys in 53, and 72-73-74-76.

- Same as preceding step, but also with stuck code 1 in reach 103, 2 in reach 59, 3 in reach 47, 4 in reach 86, 8 in reach 97.

- Maximum response time mode; small commercial fleet, convoy flags off. Five runs to check stuck codes 1, 2, 3, 4, 5 (stuck at upper end of reach due to resistance, stuck at upper end of reach in a turn, stuck at lower end of reach due to resistance, stuck at lower end of reach in a turn, stuck at either end of the reach) in reach 103.

- Five runs, same as above, but stuck in reaches 103, 59, 47, 97.

- One run, with stuck code 1 in reach 103, 2 in reach 59, 3 in reach 47, 4 in reach 86, 5 in reach 97.

- One run with no ships stuck, but convoy in reaches 50-51.

- Same as preceding step, but with large commercial fleet, also with convoys in reaches 53 and 72-73-74-76.

- Same as preceding step, but also with stuck code 1 in reach 103, 2 in reach 59, 3 in reach 47, 4 in reach 86, 5 in reach 97.

6.2.2 Phase 2 of the Validation - 1975-76 Run

As with any computer simulation, the results obtained are only as good as the basic input data and rules and assumptions. Every effort was made to ensure the simulation represented the Great Lakes-St. Lawrence Seaway System as realistically as possible. In doing so, use was made of knowledge and experience collected by interviewing USCG operations personnel at the outset of this contract and, in addition, of knowledge gained as a result of the SPAN Study [8], ice model testing in our towing basin, full-scale test programs on the Great Lakes, the Great Lakes Harbor Study [10], and conversations with ship operators, port officials, and personnel at the Coast Guard, MarAd, U.S. Army Corps of Engineers, and St. Lawrence Seaway Development Corporation. As much detail as possible was included in the algorithms while keeping execution of the simulation inexpensive enough to be used as a planning tool to identify problem areas and bottlenecks to extended season navigation and to evlauate potential improvements, particularly the allocation of icebreaker support.

The real test of how realistically the simulation represents the Great Lakes-St. Lawrence Seaway System is by validation--and the degree to which the simulation is validated is a direct measure of its credibility. Much effort had already been given to validating the original simulation, particularly in regard to the commercial vessel transit times and freight rates, which is described in Volume II of Reference [1]. In validating any simulation, one would naturally like to have as much available historical data, as possible, not only for use in the validation but also for use in developing and refining the algorithms themselves. For this particular simulation, only limited data exists and, in fact, for parts of the system, the data is practically nonexistent; the simulation should therefore be periodically revalidated as more data becomes available through continued shipping in the extended season. With these thoughts in mind, both ship and icebreaker performance were validated by comparing their performance to available historical data, since both play an equally important role in the simulation.

The 1975-76 severe winter was run with the Coast Guard icebreaker fleet listed in Table 6.5 and the cargo routes and tonnages listed in Table 6.6 For

TABLE 6.5

1975-76 VALIDATION ICEBREAKER ASSIGNMENTS

Home Port	Icebreaker	Class
Thunder Bay (Canadian)	ALEXANDER HENRY	D
Sault Ste. Marie	ARUNDEL	D
	NAUGATUCK	D
	RARITAN	D
	MACKINAW	B
St. Ignace	SUNDEW	D
	WOODRUSH	D
	WIND	B
Green Bay	MESQUITE	D
Port Huron	BRAMBLE	D
Detroit	KAW	D
	MARIPOSA	D
Toledo	OJIBWA	D
Toronto (Canadian)	NORMAN MCLEOD ROGERS	D
Oswego	(Dummy)	D
Quebec (Canadian)	LOUIS ST. LAURENT	B

TABLE 6.6

LAKER ROUTES AND TONNAGES
FOR 1975-76 VALIDATION

Route	Origin	Destination	Cargo (Thousands of Short Tons)
		------Iron Ore------	
1	Escanaba	Cleveland	832
3	Escanaba	Chicago	724
6	Two Harbors	Toledo	546
7	Two Harbors	Detroit	609
8	Two Harbors	Chicago/Gary	6981
9	Thunder Bay	Cleveland	81
12	Thunder Bay	Chicago	320
		TOTAL IRON ORE	10093
		------Coal------	
18	Toledo	Detroit	3000
		TOTAL COAL	3000

validation purposes, the Coast Guard provided copies of its 1975-76 Great Lakes Icebreaking Assistance Reports. These logs showed:

- Date of assistance
- Name of ship assisted
- User of ship assisted
- Cargo data (type, tonnage)
- Port of departure and port of destination
- Name of assisting icebreaker
- Geographical area of assistance
- Hours underway
- Mission miles
- Miscellaneous remarks

If one (or more) icebreakers simultaneously escorted more than one ship (i.e., a convoy), this was noted under "remarks". These logs were analyzed on an icebreaker-by-icebreaker basis to compile the statistics for comparing the validation run to historical data.

Table 6.7 summarizes these statistics on the lines labeled "USCG Log", grouped by task command and by period. The line labled "Simulation" is the validation run output for comparison. Data given includes:

- Number of direct assists
- Number of convoyed (simultaneous) assists
- Hours of assistance (direct plus convoyed)
- Miles of assistance (direct plus convoyed)
- Average time per assist (hours/assist)

The agreement between the Coast Guard log and the simulation is best in the Taconite task command where the commercial traffic is most accurately modeled. In particular, the average hours per assist of 8.98 is very close to the USCG Log's 8.40. Agreement in the other task commands is not as good because traffic (primarily tug/barge transits) existed and was not included in the simulation. This significantly alters the icebreaking statistics. For example, in the Coal Shovel Task Command, many assists were logged to the fuel barge traffic on the Sarnia to Detroit route. Of the 934 hours, a total of 640 hours were by two or more icebreakers simultaneously assisting tows operated by the Hannah Waterways Company in the St. Clair River. In a similar manner, the hours per assist in the Oil Can Task Command is high because Green

TABLE 6.7

SUMMARY OF 1975-76 VALIDATION RUN

		PERIOD																		TOTAL	
		2		3		4		5		6		7		8		9		10			
Assists		DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C
Taconite	USCG Log	1	0	1	0	27	0	39	11	24	15	10	6	11	6	18	11	3	3	134	52
	Simulation	0	0	0	0	4	42	0	35	0	22	0	21	0	13	0	32	0	2	4	167
Oil Can	USCG Log	4	0	0	0	1	0	4	0	2	0	0	0	0	0	2	0	1	0	14	0
	Simulation	0	0	0	0	4	0	0	0	12	0	1	0	7	0	0	0	0	0	24	0
Coal Shovel	USCG Log	0	0	7	1	28	2	16	4	8	0	0	0	0	0	0	0	7	2	66	9
	Simulation	0	0	0	0	0	26	0	17	0	1	0	4	0	24	0	57	0	0	0	129

		2	3	4	5	6	7	8	9	10	TOTAL	Average Hours/Assist
Hours												
Taconite	USCG Log	32	1	97	395	423	157	190	348	27	1670	8.98
	Simulation	0	0	350	262	181	171	126	309	37	1436	8.40
Oil Can	USCG Log	31	0	1	26	47	0	0	31	0	136	9.71
	Simulation	0	0	78	0	301	24	211	12	0	626	26.08
Coal Shovel	USCG Log	0	86	268	447	106	0	0	0	27	934	12.45
	Simulation	0	0	39	24	2	6	37	88	1	197	1.53
Miles												
Taconite	USCG Log	330	5	665	1741	1616	907	763	1737	1926	9690	
	Simulation	0	0	3618	2582	1768	1578	1066	2166	408	13186	
Oil Can	USCG Log	202	0	4	133	178	0	0	239	6	762	
	Simulation	0	0	784	0	3462	308	2352	158	0	7064	
Coal Shovel	USCG Log	0	508	1347	1233	213	0	0	0	45	3346	
	Simulation	0	0	333	207	18	54	315	756	9	1692	

Notes: 1. Convoys in reaches 51, 74, periods 1 to 9.
2. DA = Direct Assist; C = Convoy.

Bay was used for the icebreaker home port, whereas Escanaba was actually used in the extended season because the traffic out of Northern Lake Michigan (during the extended season) was entirely out of Escanaba in the validation year.

It should also be noted that a "convoy" on the Coast Guard log is not as rigorously categorized as in the simulation; that is, once the simulation defines a reach as a convoy reach, *all* ships must convoy through it, and a convoy of one ship is still called a convoy. On the other hand, a convoy of one ship in the Coast Guard log looks like a direct assist. For this reason, comparing the number of direct assists and number of convoys between the log and the simulation is not as accurate a comparison as comparing the total number of assists as shown below:

	USCG Log	Simulation
Taconite	186	171
Oil Can	14	24
Coal Shovel	75	129

Examining the above and the time per transit, it was concluded after review with U.S. Coast Guard representatives, that the simulation satisfactorily modeled icebreaker support on the Great Lakes.

6.2.3 Phase 3 of the Validation - Maximum Response Time

The same input conditions as for Phase 2 were run in the maximum response time (MRT) mode. The MRT for each reach which is tabulated below:

MRT (HOURS) VALUES FOR VALIDATION

REACH	MRT	REACH	MRT	REACH	MRT	REACH	MRT	REACH	MRT
41	7	54	33	67	15	80	13	93	7
42	9	55	49	68	21	81	9	94	13
43	15	56	23	69	31	82	25	95	31
44	19	57	17	70	19	83	17	96	31
45	17	58	37	71	21	84	19	97	57
46	23	59	19	72	7	85	9	98	89
47	45	60	9	73	9	86	31	99	129
48	47	61	11	74	3	87	25	100	143
49	25	62	21	75	5	88	7	101	211
50	9	63	9	76	9	89	11	102	15
51	11	64	17	77	7	90	7	103	31
52	9	65	13	78	13	91	29		
53	11	66	23	79	7	92	33		

was equal to the time that an icebreaker would require to get to the furthest point in the reach from the closest home port traveling at 10 mph. Table 6.8

TABLE 6.8

SUMMARY OF 1975-76 VALIDATION RUN (MRT MODE)

		PERIOD																			
		2		3		4		5		6		7		8		9		10		TOTAL	
Assists		DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C	DA	C
Taconite	USCG Log	1	0	1	0	27	0	39	11	24	15	10	6	11	6	18	11	3	3	134	52
	Simulation	0	0	0	0	4	41	0	35	0	22	0	21	0	15	0	28	0	2	4	164
Oil Can	USCG Log	4	0	0	0	1	0	9	0	2	0	0	0	0	0	2	0	1	0	14	0
	Simulation	0	0	0	0	4	0	0	0	13	0	0	0	7	0	1	0	0	0	25	0
Coal Shovel	USCG Log	0	0	7	1	28	2	16	4	8	0	0	0	0	0	0	0	7	2	66	9
	Simulation	0	0	0	0	0	26	0	16	0	1	0	6	0	24	0	56	0	1	0	130

		2	3	4	5	6	7	8	9	10	TOTAL
Hours											
Taconite	USCG Log	32	1	97	395	423	157	190	348	27	1670
	Simulation	0	0	388	294	195	199	199	316	24	1615
Oil Can	USCG Log	31	0	1	26	47	0	0	31	0	136
	Simulation	0	0	79	0	339	0	221	23	0	662
Coal Shovel	USCG Log	0	86	268	447	106	0	0	0	27	934
	Simulation	0	0	46	26	2	11	44	96	6	231
Miles											
Taconite	USCG Log	330	5	665	1741	1616	907	763	1737	1926	9690
	Simulation	0	0	3527	2300	1334	1334	1058	1518	212	11283
Oil Can	USCG Log	202	0	4	133	178	0	0	239	0	762
	Simulation	0	0	784	0	4350	0	2868	324	0	8326
Coal Shovel	USCG Log	0	508	1347	1233	213	0	0	0	45	3346
	Simulation	0	0	360	198	18	81	342	738	52	1789

shows the number of assists, total hours, and total miles for the Taconite, Oil Can, and Coal Shovel task commands as a function of time. These results are essentially the same as those in the fixed fleet mode run (Table 6.7) which indicates that the same assistance pattern was reproduced in the MRT mode. That is, the same ships were stuck in the same places at the same time. Specifically, in Taconite there were a total of 4 direct assists and 167 convoys in the fixed fleet mode run versus 4 direct assists and 164 convoys in the MRT mode run. Similarly, in Oil Can there were 24 direct assists and no convoys in the fixed fleet mode run and 25 direct assists and no convoys in the MRT mode run, while in Coal Shovel there were no direct assists and 129 convoys in the fixed fleet mode run and no direct assists and 130 convoys in the MRT mode run. The time and mileage of the assists changed somewhat due to the different fleet mix/home port combinations that the MRT mode run produced. It also should be noted that in the convoy mode of operations the MRT and the fixed fleet modes are almost identical.

Table 6.9 shows the icebreaker fleet that was generated by the MRT simulation run, by Task Command, icebreaker class, and period. The maximum icebreaker requirements were 4 in Taconite Task Command in period 4, 2 in the Oil Can Task Command in periods 6 and 8, and 1 in the Coal Shovel Task Command in periods 4 through 10. As discussed previously, commercial traffic was best modeled in Taconite, where there were fewer barge transits during the extended season. The MRT run produced a maximum of 2 icebreakers in Sault Ste. Marie, and 2 in St. Ignace, for a total of 4 in Taconite. The Coast Guard assignments in Table 6.5 had 4 in Sault Ste. Marie and 3 in St. Ignace. It should be noted that only Class D icebreakers were generated by the simulation. This is because the simulation generates the least capable icebreaker that can still perform the required task. To prevent this from occurring on future runs will require a slight modification to MRT module to prohibit Class D icebreakers from being generated. Without barge traffic and realizing additional icebreaker support would be used for preventive icebreaking and channel maintenance, the MRT output appears reasonable, and it was concluded that the MRT mode functioned correctly.

6.2.4 Phase 4 of the Validation - Transit Times

Another source of validation data for the simulation is a ship's calculated round trip time on a route for which there is historic data readily available. The only readily available data showing exact vessel transit time of a significant portion of the extended navigation season and for several years was the Two Harbor-to-Gary iron ore route from reference [1], updated from reference [11]. This historical data is superimposed on the predictions obtained from production runs of the simulation in Figures 6.1 through 6.3 for laker ship classes 5, 8, and 10 respectively. While there is a large amount of fluctuation in the data, good agreement existed for the normal season, and there was no substantial disagreement in the extended season, recognizing the large amount of scatter in the historical data. Note for example that the peak transit times indicated by the simulation to occur in periods 5-6 of the normal winter (1975-76) actually occurred in the 1975-76 data points.

TABLE 6.9

ICEBREAKER FLEET GENERATED BY
1975-76 VALIDATION RUN (MRT MODE)

	PERIOD									
	1	2	3	4	5	6	7	8	9	10
Taconite										
Class D	0	0	0	4	2	1	1	2	2	1
Class C	0	0	0	0	0	0	0	0	0	0
Class B	0	0	0	0	0	0	0	0	0	0
Oil Can										
Class D	0	0	0	1	0	2	0	2	1	0
Class C	0	0	0	0	0	0	0	0	0	0
Class B	0	0	0	0	0	0	0	0	0	0
Coal Shovel										
Class D	0	0	0	1	1	1	1	1	1	1
Class C	0	0	0	0	0	0	0	0	0	0
Class B	0	0	0	0	0	0	0	0	0	0

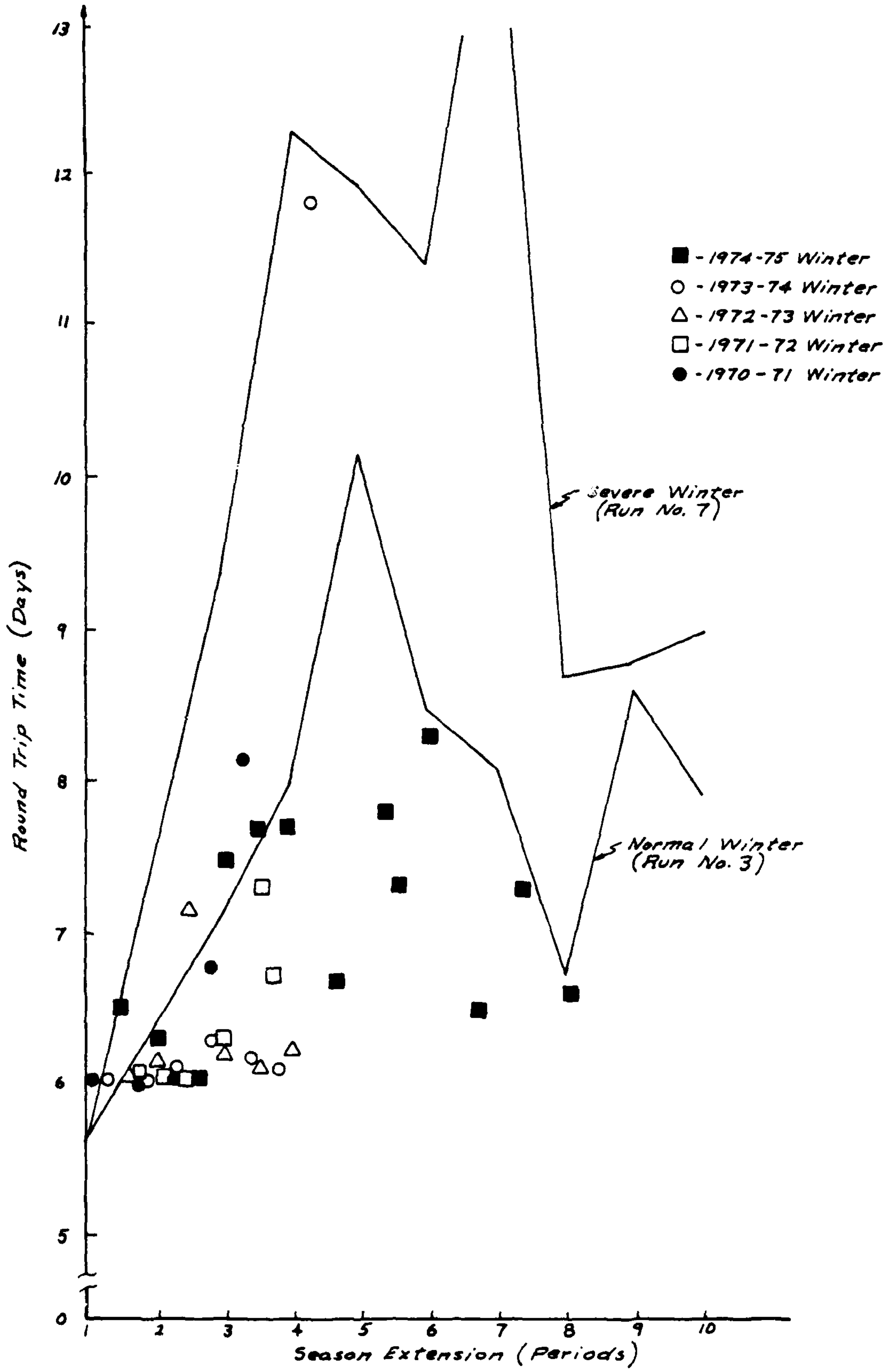

Figure 6.1 Round Trip Time From Two Harbors to Gary for Class 5 Laker Vessel

AD-A082 164 ARCTEC INC COLUMBIA MD F/G 15/5
COMPUTER SIMULATION OF GREAT LAKES-ST. LAWRENCE SEAWAY ICEBREAK--ETC(U)
JAN 80 T V KOTRAS, J J PETER DOT-CG-81-78-1953
UNCLASSIFIED 296C-4 USCG-D-56-79 NL

2 of 3
AD
A082164

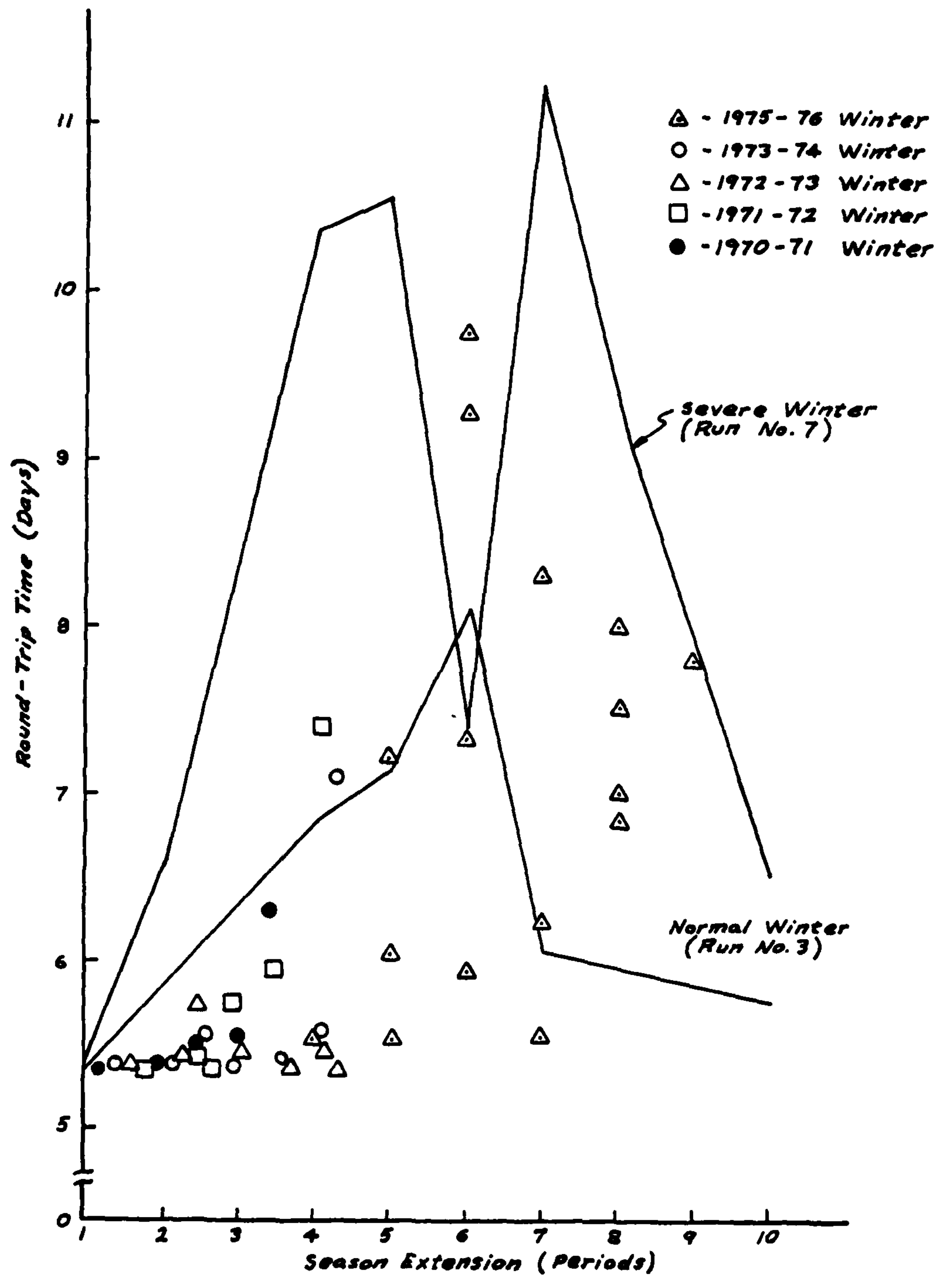

Figure 6.2 Round Trip Time From Two Harbors to Gary for Class 8 Inland Vessel

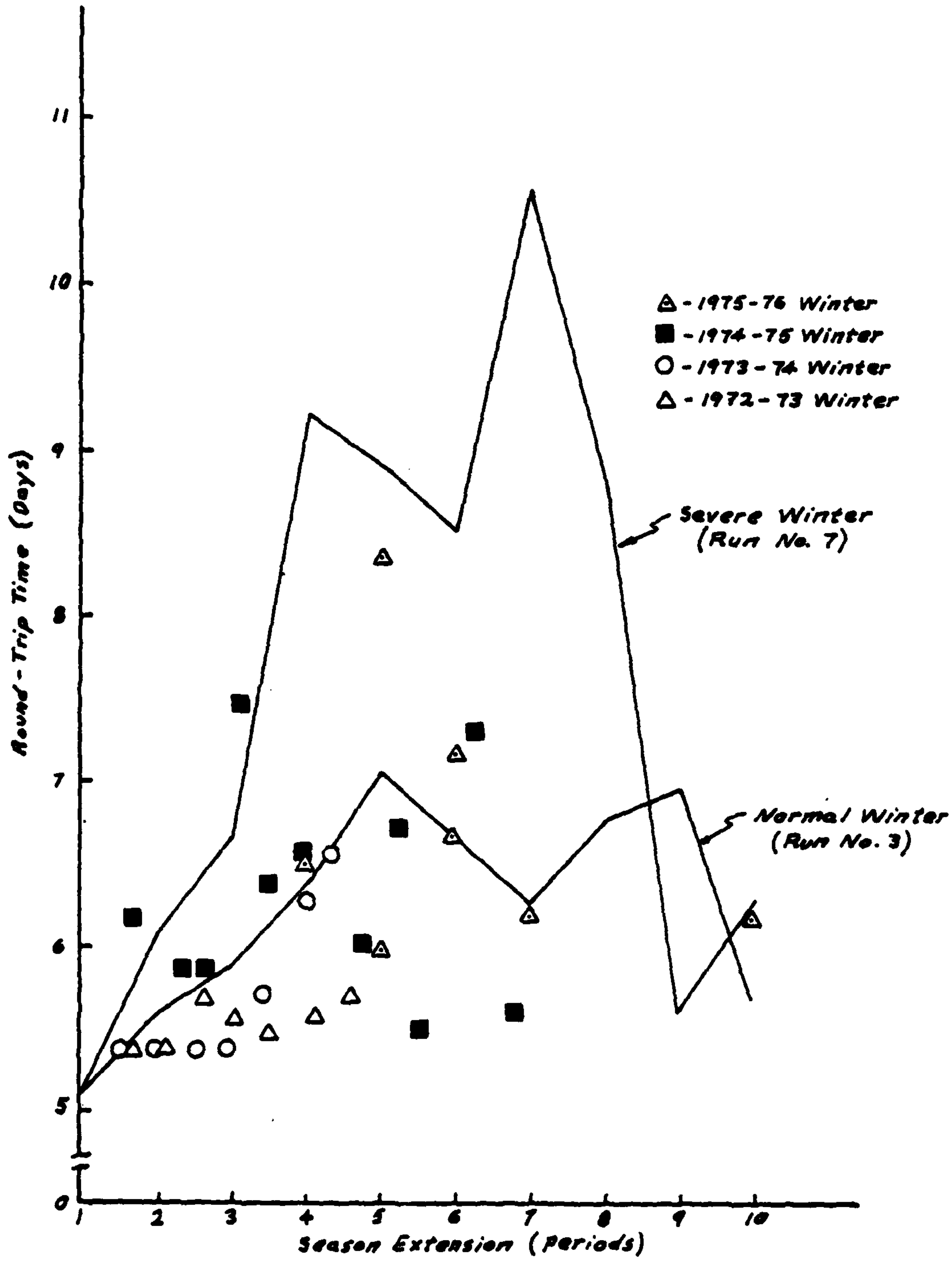

Figure 6.3 Round Trip Time From Two Harbors to Gary for Class 10 Laker Vessel

6.3 Summary of Production Run Results

In order to assess the nine effects and comparisons listed in Section 6.1, ten (10) production runs tabulated in Table 6.10a, b were executed. The commercial vessel fleet used in those runs was tonnage driven; that is, vessels on each route were generated on a frequency basis to carry a specified amount of cargo over the extended season. Tables 6.11 and 6.12 give a list of the cargo routes and tonnages to be carried over the 126 days (4.14 months) of the simulation's extended season. These extended season tonnage projections were calculated from data supplied by the North Central Division of the U.S. Army Corps of Engineers and correspond to the most recent tonnage projection for the year 2000 made as part of the Great Lakes-St. Lawrence Seaway Navigation Season Extension Program. Detailed output of each simulation run has been provided to the Coast Guard separately as computer printout. Summary tables of the production runs outlining the input run conditions, fixed icebreaker fleet or MRT generated icebreaker fleet (by icebreaker class, task command and time period), icebreaker operating statistics for each icebreaker task command (by icebreaker class and period), and extended navigation season tonnage (by commodity and route) are presented in Section 6.4.

The comparisons of those ten (10) production runs are made in Tables 6.13 through 6.21 to assess the following nine effects and comparisons:

Run Numbers	Effect of Comparison	Table Number	Page Number
1,4	Effect of Increased Cargo Tonnage (20%)	6.13	6-29
2,3	Effect of Increased Maximum Response Time	6.14	6-30
3,6	Effect of Convoying	6.15	6-31
3,1	Comparison of MRT and Fixed Fleet for Normal Winter	6.16	6-32
3,7	Effect of Winter Severity	6.17	6-33
7,5	Effect of Prohibiting Class C Icebreakers from Convoying	6.18	6-34
7,8	Effect of Increased Low SHP/Length Restrictions	6.19	6-35
8,9	Effect of Channel Clearing	6.20	6-36
8,10	Comparison of MRT and Fixed Fleet for Severe Winter	6.21	6-37

TABLE 6.10a

PRODUCTION RUNS FOR SIMULATION OF
GL-SLS ICEBREAKER REQUIREMENTS

RUN NO.	WINTER TYPE	MINIMUM LAKER CLASS	RUN MODE[1]	USCG ESTIMATED FLEET	MRT (hr)	CONVOYING IB TYPES[2]	CHANNEL CLEARING[2] (in/2wks)	CARGO TONNAGE (year)
1	Normal	5	FIBF	Normal[5]	---	C,B	---	2000
2	Normal	5	MRT	---	Min[3]	C,B	---	2000
3	Normal	5	MRT	---	Min+12	C,B	---	2000
4	Normal	5	FIBF	Normal[5]	---	C,B	---	2000+20%
6	Normal	5	MRT	---	Min+12	No Convoys	---	2000
5	Severe	5	MRT	---	Min+12	B	---	2000
7	Severe	5	MRT	---	Min+12	C,B	---	2000
8	Severe	6	MRT	---	Min+12	C,B	---	2000[4]
9	Severe	6	MRT	---	Min+12	C,B	12	2000[4]
10	Severe	6	FIBF	Severe[5]	---	C,B	---	2000[4]

NOTES:

[1] FIBF = Fixed icebreaker fleet; MRT = *Maximum response time.*
[2] Convoys and channel clearing in: St. Marys River/Whitefish Bay, Straits of Mackinac, Detroit/St. Clair Rivers, Welland Canal, St. Lawrence Seaway.
[3] Minimum time is that required to get to furthest point in reach from closest home port at 5 mph.
[4] Cargo tonnage on restricted ships assumed carried in normal season.
[5] USCG estimated icebreaker fleet listed in Table 6.10b.

COMPARISONS:

1,4 -Effect of increased cargo tonnage (20%)(normal winter).
2,3 -Effect of variation in maximum response time (normal winter).
3,1 -Difference between MRT generated icebreaker fleet and fixed icebreaker fleet (normal winter)
3,6 -Effect of convoys (normal winter).
3,7 -Effect of winter severity.
5,7 -Effect of not allowing Class C icebreakers to convoy (severe winter).
7,8 -Effect of vessel class restriction (severe winter).
8,9 -Effect of channel clearing (severe winter).
8,10-Difference between MRT generated icebreaker fleet and fixed icebreaker fleet (severe winter).

TABLE 6.10b

USCG ESTIMATED FLEET FOR YEAR 2000*

Area	Home Port	Normal Winter B	Normal Winter C	Severe Winter B	Severe Winter C	Severe Winter D
S-1	Duluth	-	2	1	2	-
C-1	Sault Ste. Marie	2	4	3	6	-
C-2	St. Ignace	1	1	2	2	2
C-3	Port Huron, Detroit, Toledo	1	2	1	4	-
M-1	Escanaba	-	1	-	1	-
M-2	Chicago	-	1	1	2	-
M-3A	(NE Lake Michigan)	-	-	-	-	-
H	Saginaw	-	-	2	3	-
E-1	Sandusky	-	1	1	2	-
E-3	Buffalo	1	2	1	4	-
SL-0	Oswego	-	3	-	3	-
	SUBTOTAL	5	17	12	29	2
	TOTAL	22		43		

Note: Principal ports; operations limited to vessels of reasonably high capability (SHP/L > 6); 12 hrs per day per icebreaker.

*Letter dated 8 June 1977 from Commander, Ninth Coast Guard District to the Commandant (G-O).

TABLE 6.11 MAJOR LAKER TRADE ROUTES PROJECTED FOR YEAR 2000

Route No.	Origin Port	Destination Port	Cargo* (thousands of short tons)
	----IRON ORE----		
1	Two Harbors	Calumet/Indiana Harbor	636
2		Gary/Burns Harbor	877
3		Detroit/Windsor	483
4		Toledo	160
5		Cleveland	759
6		Ashtabula/Conneaut	763
7		SPARE	
8	Duluth/Superior	Calumet/Indiana Harbor	1249
9		Gary/Burns Harbor	1324
10		Sandusky	757
11		Lorain	844
12		Cleveland	1476
13		Ashtabula/Conneaut	1483
14		Buffalo	750
15		Toronto/Hamilton	572
16		SPARE	
17	Presque Isle	Detroit	1086
18		SPARE	
19	Taconite	Calumet/Indiana Harbor	743
20		Gary/Burns Harbor	422
21		Detroit/Windsor	262
22		Lorain	610
23		Cleveland	759
24		Ashtabula/Conneaut	884
25		SPARE	
26	Silver Bay	Calumet/Indiana Harbor	530
27		Gary/Burns Harbor	388
28		Toledo	522
29		Cleveland	972
30		Ashtabula/Conneaut	1267
31		SPARE	
32	Thunder Bay	Sault Ste. Marie	551
33		Gary/Burns Harbor	757
34		Port Colbourne	567
35		Toronto/Hamilton	471
36		SPARE	
37	Escanaba	Calumet/Indiana Harbor	955
38		Detroit/Windsor	808
39		Toledo	838
40		SPARE	

* Tonnage projection for nine 14-day periods of season extension (4.14 mos.)

TABLE 6.11 MAJOR LAKER TRADE ROUTES
PROJECTED FOR YEAR 2000 (CON'T)

Route No.	Origin Port	Destination Port	Cargo* (thousands of short tons)
	--IRON ORE CON'T--		
41**	Sept. Isle	Calumet/Indiana Harbor	610
42**		Cleveland	893
43		SPARE	
		TOTAL IRON ORE	27028
	-------COAL-------		
44	Duluth/Superior	Milwaukee/Port Washington	969
45		Port Huron/St. Clair	944
46		Detroit/Windsor	944
47		Cleveland	416
48		Buffalo	2497
49		Toledo/Monroe	907
50		SPARE	
51	Thunder Bay	Port Colbourne/Nanticoke	1026
52		SPARE	
53	Calumet/Indiana Harbor	Taconite	184
54		Milwaukee/Port Washington	849
55		SPARE	
56	Toledo	Duluth/Superior	115
57		Presque Isle/Marquette	108
58		Green Bay	221
59		Escanaba	210
60		Buffalo	507
61		Sault St. Marie	1698
62		SPARE	
63	Sandusky	Presque Isle/Marquette	153
64		Escanaba	246
65		Buffalo	204
66		Toronto/Hamilton	1260
67		SPARE	
68	Ashtabula/Conneaut	Duluth/Superior	193
69		Presque Isle/Marquette	188
70		Green Bay	380
71		Buffalo	537
72		Toronto/Hamilton	2417
73		SPARE	
		TOTAL COAL	18153

* Tonnage projection for nine 14-day periods of season extension (4.14 mos.)
** Triangular route

TABLE 6.11 MAJOR LAKER TRADE ROUTES
PROJECTED FOR YEAR 2000 (CON'T)

Route No.	Origin Port	Destination Port	Cargo* (thousands of short tons)
	------GRAIN------		
74	Duluth/Superior	Calumet/Indiana Harbor	32
75		Detroit/Windsor	35
76		Cleveland	18
77		Buffalo	599
78**		Baie Comeau	1916
79		SPARE	
80	Milwaukee/Port Wash.	Buffalo	44
81		Baie Comeau	84
82		SPARE	
83	Calumet/Indiana Harbor	Buffalo	35
84		SPARE	
85	Toledo	Baie Comeau	50
86		SPARE	
		TOTAL GRAIN	2813

* Tonnage projection for nine 14-day periods of season extension (4.14 mos.)
** Triangular route

TABLE 6.12

SIMULATION SALTY TRADE ROUTES
PROJECTED FOR YEAR 2000

ROUTE NO.	ORIGIN PORT	DESTINATION PORT	CARGO (THOUSANDS OF SHORT TONS)
	------General Cargo------		
87	World Area 1	Schedule 1	485
	------Ballast In/Grain Export------		
88	Duluth/Superior	World Area No. 1	3183
89	Thunder Bay	World Area No. 1	2123
90	Calumet/Indiana Harbor	World Area No. 1	590
	TOTAL (including triangular routes below)		5986
	------Iron & Steel Import/Grain Export (Triangular Route)------		
91	World Area No. 1	Milwaukee/Port Washington	279
92	World Area No. 1	Detroit/Windsor	388
93	World Area No. 1	Toledo	545
	TOTAL		1112

TABLE 6.13

EFFECT OF INCREASED CARGO TONNAGE ON SYSTEM[1]

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
1	Normal	5	USCG Est. Normal Winter	N.A.	Classes C & B	None	~63,000,000 Short Tons
4	Normal	5	USCG Est. Normal Winter	N.A.	Classes C & B	None	~74,900,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	For both runs, a fixed fleet of 10 icebreakers (7 Class C and 3 Class B) were utilized almost 100% in periods 5-9. As a result, when tonnage was increased by almost 20%, the already large queues (Run 1) increased significantly.	For both runs, a fixed fleet of 2 Class C icebreakers were capable of handling the demand for their services with an average icebreaker utilization of 44% (Run 1) and 46% (Run 4) for periods 5-9. It should be noted that during 2-week periods 6 and 8, the utilization increased significantly to 95% and 80% for Run 1 and 95% and 84% for Run 4.	For both runs, a fixed fleet of 7 icebreakers (5 Class C and 2 Class B) were capable of handling the demand for their services with the exception of period 6 when all seven were utilized 100%.	For both runs, a fixed fleet of 3 Class C icebreakers were utilized 100% during periods 5 through 8 convoying ships through the Seaway.
Direct Assists	The total number of assists increased by 17.4% from 781 (Run 1) to 917 (Run 4). This increase is approximately the same as the increase in tonnage.	The total number of assists increased by 10% from 80 (Run 1) to 88 (Run 4). This increase is significantly below the tonnage increase due to large queues in Taconite Command.	The number of assists increased by 17.5% from 200 (Run 1) to 235 (Run 4). This increase is approximately the same as the tonnage increase.	There were no direct assists in this task command.
Convoys	The total number of convoys escorted increased by 16.1% from 629 (Run 1) to 730 (Run 4). Since this increase in percentage is somewhat less than the increase in tonnage, the faster arrival rate of vessels at convoy points enables more ships to be escorted per convoy before the time limit expired for the first ship.	There were no convoys in this task command.	There were no convoys in this task command.	The number of convoys increased by 8.7% from 173 (Run 1) to 188 (Run 4). This is *much* less than the increase in tonnage, and indicates that many convoys in Run 1 consisted of fewer ships than those in Run 4.
Queues	The increase in tonnage caused the average size of queues to increase significantly. Direct Assistance queues increased by 32% from an average of 6.8 (Run 1) to 9 (Run 4).	The Direct Assistance queues were small, having only 1 or 2 ships in both runs during periods 6 and 8.	The average Direct Assistance queue increased in period 6 from 2 ships to 6 ships, while in all other periods the queues were very small.	The average convoy queues increased significantly from an average of 5.5 ships for Run 1 to almost 12 ships for Run 4.

1. *In the fixed icebreaker fleet mode*, an icebreaker is *free to respond* anywhere in the task command, while for the maximum response time mode an icebreaker may respond only in those reaches with the same home port. As a result, the fixed fleet in Taconite is utilized inefficiently because a major amount of time is spent travelling between Duluth/Superior area and the Soo.

TABLE 6.14

EFFECT OF INCREASED MAXIMUM RESPONSE TIME ON ICEBREAKER REQUIREMENTS

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
2	Normal	5	Max. Response Time Mode	Minimum	Classes C & B	None	~63,000,000 Short Tons
3	Normal	5	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	~63,000,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	The effect of increasing the MRT by 12 hours tended to reduce the number of icebreakers generated in periods 5, 6, and 7 (9, 18, and 13 vs 6, 12 and 12) but increased the number in periods 8 and 9 (12 and 14 vs 17 and 16). In an overall sense there appears to be little difference in the generated icebreaker fleets when vessel utilization is considered; that is, for the entire winter both fleets appeared to operate at approximately 50% utilization.	The effects of increasing the MRT by 12 hours had almost no affect on the generated icebreaker fleet with 4 Class D icebreakers generated in periods 5, 7 and 9 and between 14 to 16 Class D icebreakers operating at 16% utilization in periods 6 and 8.	The effect of increasing the MRT by 12 hours had a slight effect of increasing the generated icebreaker fleet. In period 5, 18 Class D icebreakers operating at 24% utilization were increased to 20 Class D icebreakers operating at 21% utilization. In period 6, 24 Class D and 4 Class C icebreakers operating at 27% utilization were increased to 25 Class D and 5 Class C icebreakers operating at 26% utilization. This somewhat unexpected result is due to the difference in arrival of vessels requiring direct assistance as indicated by the large average direct assistance queues.	A maximum of 6 icebreakers was required in period 7 of Run 2, versus 5 in period 5 of Run 3. The fleet mix was 100% Class C icebreakers in both runs. The decrease in the number of Class C icebreakers was due to the decrease in the number of convoys escorted. In both runs, icebreaker utilization averaged approximately 80% in periods 5 through 8.
Direct Assists	A total of 789 direct assists occurred in Run 2,and 792 in Run 3.	There were 90 direct assists in Run 2, and 86 in Run 3.	There were 198 assists in both runs.	There were no direct assists in this task command.
Convoys	A total of 717 convoys were escorted in Run 2 versus 699 in Run 3, indicating that, due to the additional waiting time, some convoys consisted of a larger number of ships in Run 3.	There were no convoy routes in this task command.	No convoy routes were defined in the normal winter for this task command.	A total of 200 convoys were escorted in Run 2 versus 185 in Run 3, indicating that, with the longer MRT, some convoys may have carried more ships.
Queues	The direct assistance queue was empty in Run 2, and averaged 1 ship in Run 3.	The direct assistance queues ranged from 1 to 2 ships for Run 2 and 1 to 3 ships for Run 3.	The direct assistance queue averaged 1 ship in periods 6 and 7 for Run 2, and 2 and 3 ships in periods 6 and 7 respectively for Run 3.	There were no direct assistance queues in this task command.

TABLE 6.15

EFFECT OF CONVOYING ON ICEBREAKER REQUIREMENTS

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
3	Normal	5	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	63,000,000 Short Tons
6	Normal	5	Max. Response Time Mode	Minimum + 12 hours	*No Convoys*	None	63,200,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	The elimination of convoying increases the required icebreaker fleet from an average of 14 icebreakers (2 Class D, 8 Class C, 4 Class B) to 30 icebreakers (11 Class D, 8 Class C, 11 Class B) for periods 6 through 10. It is important to note that when convoying was used, the average icebreaker utilization was 52% while, when convoying was eliminated, the average icebreaker utilization was 32%.	Because there were no convoys in this task command, both runs generated approximately the same icebreaker fleet with 15 Class D icebreakers operating at 16% utilization in periods 6 and 8, and 4 Class D icebreakers operating at approximately 10% in periods 5, 7, and 9.	For both runs, significant icebreaker assistance was required during periods 5 and 6 to provide direct assistance aid. In Run 3, 20 Class D icebreakers were generated in period 5, and 25 Class D and 5 Class C icebreakers in period 6. In Run 6, 19 Class D icebreakers were generated in period 5, and 21 Class D and 5 Class C icebreakers in period 6. It is important to note that while a large number of icebreakers were generated they were operating at between 20% and 30% utilization.	The maximum number of icebreakers dropped from 5 Class C in period 5 for Run 3, to 4 Class C in period 7 for Run 6. This reflects the fact that salties, which were capable of proceeding on their own, were being forced to convoy thereby requiring more icebreakers.
Direct Assists	Without convoys the total number of direct assists increased from 792 to 1422, an increase of almost 80%.	Because there were no convoys in this task command, the number of direct assists were the same (86 assists for Run 3 and 85 for Run 6).	The total number of direct assists was approximately the same (198 for Run 3 and 193 for Run 6).	There were no direct assists *in Run 3 due to convoying, while* there was a total of 16 in Run 6 when convoying was *not* performed.
Convoys	In Run 3 a total of 699 convoys were escorted while in Run 6 none were escorted.	There were no convoys in this task command.	There were no convoys in this task command during a normal winter.	In Run 3 a total of 185 convoys were escorted. *In Run 6, none* were escorted.
Queues	The average direct assistance queues in Run 3 ranged from 0 to 1, while in Run 6 they ranged from 1 to 2.	For both runs, average direct assistance queues ranged from 1 ship to 3 ships waiting for assistance.	The average direct assistance queue was slightly smaller in Run 6 (1 ship in period 5 and 2 ships in period 6) compared to Run 3 (2 ships in period 5 and 3 ships in period 6).	In Run 6, average direct assistance queues were negligible.

TABLE 6.16

COMPARISON OF MAXIMUM RESPONSE TIME MODE WITH FIXED ICEBREAKER FLEET FOR A NORMAL WINTER[1]

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
1	Normal	5	USCG Est. Normal Winter	N.A.	Classes C & B	None	63,000,000 Short Tons
3	Normal	5	Max. Response Time Mode	Maximum + 12 hours	Classes C & B	None	61,000,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	The fixed icebreaker fleet consisting of 7 Class C and 3 Class B icebreakers operated at 100% utilization in periods 5 through 9 performing 781 direct assists and escorting 629 convoys. It should be noted that these icebreakers spent a large amount of time moving around between times of assistance and convoys. In periods 6 through 9, the MRT Mode generated icebreaker fleets ranged from 12 icebreakers (2 Class D, 7 Class C, 3 Class B) in period 7 to 17 icebreakers (3 Class D, 9 Class C, 5 Class B) in period 8.	The fixed icebreaker fleet consisted of 2 Class C icebreakers which operated at less than 25% utilization in all periods other than 6 and 8. In periods 6 and 8, they operated at 95% and 80% respectively, performing 80% of the total number of direct assists. In periods other than 6 and 8, the MRT Mode generated a maximum of 4 Class D icebreakers which operated at an average utilization of 10%. In periods 6 and 8, 15 and 16 Class D icebreakers were generated to perform 63 direct assists at an average utilization of 15%.	The fixed icebreaker fleet consisted of 5 Class C and 2 Class B icebreakers operating at approximately 50% utilization in period 5 to perform 70 direct assists, and at 100% utilization in period 6 to perform 119 direct assists. The MRT Mode generated a fleet of 20 Class D icebreakers operating at 21% utilization in period 5 to perform 68 direct assists, and 25 Class D and 5 Class C icebreakers operating at 26% utilization, to handle 119 direct assists.	The fixed icebreaker fleet consisted of 3 Class C icebreakers which operated at 100% utilization in periods 5 through 8 to handle 173 convoys. In periods 5 through 8, the MRT Mode generated icebreaker fleets ranged from 3 Class C fleets breakers operating at 72% utilization in period 8, to 5 Class C icebreakers operating at 82% utilization in period 5 to handle a total of 185 convoys.
Direct Assists	The total number of direct assists in the MRT Mode run was 792, while in the fixed fleet run it was 781. In the MRT Mode run (for all icebreakers), the portion of the mileage spent actually escorting was 61%, 74%, and 75% (periods 5, 6, and 7 respectively), compared to 10%, 25%, and 29% for the fixed fleet run. The rest of the miles were incurred going to the point of assistance or returning to home port.	There were 86 direct assists by Class D icebreakers in Run 3 and 80 by Class C icebreakers in Run 1.	There were 198 direct assists in Run 3 as compared to 200 in Run 1.	There were no direct assists in this task command.
Convoys	In the MRT Mode run a total of 699 convoys were processed, while the fixed fleet escorted 629. In the MRT Mode run (for all icebreakers), the portion of the mileages spent actually escorting was 74%, 70%, and 66% (periods 5, 6, and 7 respectively), compared to 20%, 58%, and 44% for the fixed fleet run.	There were no convoys in this task command.	There were no convoys specified in this task command for the normal winter.	There were a total of 185 convoys processed in Run 3 compared to 173 in Run 1, indicating that the MRT Mode fleet was escorting convoys of slightly fewer ships.
Queues	The direct assistance queue, which was negligible in the MRT Mode run, was as high as 11 ships in the fixed fleet run.	The direct assistance queue averaged 2 ships in Run 3 and zero in Run 1.	The direct assistance queue size was essentially the same.	There were no direct assistance queues in the Seaway Command.

1. In the fixed icebreaker fleet mode, an icebreaker is free to respond any where in the task command, while for the maximum response time mode an icebreaker may respond only in those reaches with the same home port. As a result, the fixed fleet in Taconite is utilized inefficiently because a major amount of time is spent travelling between Duluth/Superior area and the Soo.

TABLE 6.17

EFFECT OF WINTER SEVERITY ON ICEBREAKER REQUIREMENTS

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
3	Normal	5	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	63,000,000 Short Tons
7	Severe	5	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	67,900,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	For the normal winter, an average icebreaker fleet of 14 vessels (2 Class D, 8 Class C, and 4 Class B) was generated in periods 6 through 9. Icebreaker utilization for these vessels ranged from 8% to 91% with an average of 50%. For the severe winter, the generated icebreaker fleet ranged from 17 icebreakers (4 Class D, 13 Class C), 13 icebreakers (9 Class C, 4 Class B), 41 icebreakers (27 Class D, 11 Class C, 3 Class B), 29 icebreakers (15 Class D, 12 Class C, 2 Class B) to 12 icebreakers (2 Class D, 3 Class C, 7 Class B) in periods 5 through 9 respectively. The utilization of these vessels ranged from 9% to 86% with an average of 50%.	For the normal winter, an icebreaker fleet of 4, 16, 4, 16, and 3 Class D icebreakers was generated in periods 5, 6, 7, 8 and 9 respectively. These icebreakers operated at an average utilization of 14%. For the severe winter, an icebreaker fleet of 2 Class D, 8 Class D, 3 Class D icebreakers in periods 3, 4, and 5 were generated. In periods 6 and 7, an icebreake. fleet of 4 vessels (1 Class D and 3 Class C) and 7 vessels (3 Class C and 4 Class B) were generated respectively. The reason for this seemingly contrary trend is that in the severe winter ships were stuck in a reach much closer to the home port (see below). This is a result of using actual historic data which sometimes is inconsistent.	For the normal winter, the generated icebreaker fleet ranged from 20 Class D icebreakers in Perid 5, 30 icebreakers (25 Class D, 5 Class C) in period 6 to 5 Class D icebreakers in Period 7. Icebreaker utilization ranged from 7% to 29% with an average of 22%. For the severe winter, the generated icebreaker fleet varied from 53 icebreakers (42 Class D, 7 Class C, 4 Class B) in period 5, 54 icebreakers (42 Class D, 7 Class C, 5 Class B) in period 6, 50 icebreakers (3 Class D, 42 Class C, 5 Class B) in period 7, to 22 icebreakers (16 Class D, 4 Class C, 2 Class B) in period 8. Icebreaker utilization ranged from 12% to 80% with an average of 40%.	For the normal winter, between 3 and 5 Class C icebreakers, operating at 80% utilization, were generated in periods 5 through 8 to handle 184 convoys. For the severe winter, the generated icebreaker fleet varied from 6 icebreakers (1 Class D and 5 Class C) in period 5, 11 Class C icebreakers in period 6, 4 Class B icebreakers in period 6 to 3 icebreakers (1 Class D, 2 Class B) in period 8. Icebreaker utilization ranged from 32% to 84% with an average of 49%.
Direct Assists	The total number of direct assists increased from 792 in the normal winter to 1032 in the severe winter, an increase of 30%.	There were 86 direct assists in the normal winter run and 102 in the severe run. However, these required a total of 1936 hours (for 18507 miles) in the normal winter and only 1340 (for 7734 miles) in the severe winter. In the normal winter ships were stuck most often in reach 55, whereas in the severe run ships most often required assistance in reach 56, which is much closer to the home port of Escanaba.	There were 198 direct assists in the normal winter as compared to 573 in the severe winter, an increase of 189%.	There were no direct assists in the normal winter and 40 in the severe winter.
Convoys	The convoy routes were defined over longer periods of time for the severe winter, which resulted in an increase of escorted convoys from 699 to 937, an increase of 34%.	There were no convoy routes defined in this task command.	Convoys in the Detroit/St. Clair River System were operated only in the severe winter when 347 convoys were escorted.	The convoy route was defined for the same time periods in both runs. 185 convoys were escorted in the normal winter as compared to 154 in the severe winter. Fewer convoys were required because Class B icebreakers were generated in periods 7 and 8, and can handle twice as many ships per convoy as Class C icebreakers.
Queues	Queues were higher in the severe winter with average direct assistance queues increasing from a maximum of 1 ship to 5 ships.	The average direct assistance queues increased from a maximum of one ship for the severe winter to a maximum of 3 ships for the normal winter.	In the normal winter there were no convoy queues and the direct assistance queue was no larger than 3 ships. In the severe winter the average direct assistance queue reached 5 ships.	The size of the convoy queues was essentially unchanged, averaging approximately 3 ships.

TABLE 6.18

EFFECT OF PROHIBITING CLASS C ICEBREAKERS FROM CONVOYING

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
5	Severe	5	Max. Response Time Mode	Minimum + 12 hours	Class B Only	None	62,900,000 Short Tons
7	Severe	5	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	62,900,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	The number of required icebreakers varies from a maximum of 41 in period 7 of Run 2 to 39 in Run 5 because of the larger convoying capability of Class B icebreakers. Over all periods the average number of icebreakers required was decreased by 21%.	Since there are no convoys in Oil Can, the generated icebreaker fleet was approximately the same with 2 Class D icebreakers, 8 Class D icebreakers, 4 icebreakers (1 Class D, 3 Class C) and 7 icebreakers (3 Class C and 4 Class B) in periods 3 through 7 respectively. For Run 5 in period 6, one of the Class C icebreakers was replaced with a Class D icebreaker. Icebreaker utilization ranged from 11% to 34% with an average of 17%.	Prohibiting convoying by Class C icebreakers did not significantly reduce the total number of icebreakers generated during the severe part of the winter (periods 5, 6, and 7), but did replace the number of Class C icebreakers with an almost equal number of Class B icebreakers. This indicated that the increased convoying capacity of Class B icebreakers could not be fully utilized.	The maximum number of icebreakers required changed from 11 Class C operating at 71% utilization in period 6 for Run 7, to 5 icebreakers (1 Class C and 4 Class B) operating at 75% utilization in period 6 for Run 5.
Direct Assists	There were essentially the same number of direct assists in both runs (1032 versus 1036). 64% as much time was spent in direct assists as convoying in Run 7.	The number of direct assists was essentially the same (102 versus 103).	The number of direct assists was almost the same, 573 in Run 7 and 583 in Run 5.	The number of direct assists were essentially the same in both runs (40 versus 42).
Convoys	The number of convoys decreased from 937 to 581 because of the larger convoying capacity of the Class B icebreaker (6 versus 3).	There were no convoy routes defined in this task command.	The number of convoys escorted was reduced from 347, all by Class C icebreakers, in Run 7 to 177, all by Class B icebreakers, in Run 5, reflecting that more ships were escorted per convoy.	The number of convoys decreased from 154 to 133, again reflecting the increased convoying capacity of the Class B icebreakers.
Queues	The size of the queues remained approximately the same with average direct assistance queues ranging from 1 ship to 6 ships.	The queue size was negligible.	The average queue sizes remained approximately the same with direct assistance queues ranging from 1 ship to 6 ships.	The queue sizes remained approximately the same with maximum direct assistance queues of 1 ship.

TABLE 6.19

EFFECT OF INCREASED LOW SHP/LENGTH RESTRICTION ON ICEBREAKING REQUIREMENTS

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
7	Severe	5	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	~62,900,000 Short Tons
8	Severe	6	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	~54,800,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	The maximum number of icebreakers required decreased significantly from 41 in period 7 when Class 5 Lakers are allowed to operate, to 12 in period 8 when Class 5 Lakers are not allowed to operate.	The restriction of Class 5 Lakers from operating reduced the required icebreaker fleet from a maximum of 8 Class D icebreakers in period 4 and 7 icebreakers (3 Class C and 4 Class B) in period 7, to 1 Class D icebreaker in period 6 and 4 icebreakers (1 Class D, 3 Class C) in period 7. The icebreaker utilization for both runs averaged less than 25%.	For all periods other than 7, the number of required icebreakers decreased by a factor of 2 by restricting the movement of Class 5 Lakers and the elimination of convoying in the Detroit/St. Clair System. In period 7 the number of icebreakers were approximately the same (50 for Run 7 and 52 for Run 8) due to a 45% icebreaker utilization in Run 7 and a 27% icebreaker utilization in Run 8.	The restriction of Class 5 Lakers from operating reduced the required icebreaker fleet from a maximum of 11 Class C icebreakers to 8 Class C icebreakers in period 6. It should be noted that in period 7 more icebreakers (4 Class B vs 5 Class B) were required in Run 8 due to an increased number of convoys. Also it should be noted that in period 8, 1 Class D and 2 Class B icebreakers were required in Run 7, while 2 Class D and 3 Class B icebreakers were required in Run 8. This apparent discrepancy can be explained by looking at the icebreaker utilization where in Run 7 the 2 Class B icebreakers are operating at 82% while in run 8 the 3 Class B icebreakers are operating at 50%.
Direct Assists	The total number of direct assists decreased from 1032 in Run 7 to 671 in Run 8, due to prohibiting Class 5 Lakers from operating.	The number of direct assists decreased from 102 to 11 when Class 5 Lakers were restricted from operating.	The total number of direct assists decreased from 573 to 337 due to prohibiting Class 5 Lakers from operating.	The total number of direct assists decreased from 40 to 23 with the restriction placed on Class 5 Lakers.
Convoys	For Run 8, the starting time for the convoys was delayed 2 periods and the length of the St. Marys River convoy was cut by half. As a result the number of convoys escorted decreased from 937 to 587, and the number of hours spent convoying decreased from 13651 to 6511 hours.	There were no convoy routes defined for this task command.	A total of 347 convoys were escorted in Run 7. No convoy route was defined for Run 8 so none were escorted.	The total number of convoys escorted decreased only slightly from 160 to 154 with the imposed restriction on Class 5 Lakers.
Queues	The size of the direct assistance queue was reduced from a maximum of 5 to 2.	The direct assistance queue was negligible.	In Run 7, average direct assistance queues were approximately 4 ships while average direct assistance queues were approximately 3 ships in Run 8.	In Run 7, direct assistance queues averaged 1 ship in periods 6 and 7, while in Run 8 no direct assistance queues occurred.

TABLE 6.20

EFFECT OF CHANNEL CLEARING ON ICEBREAKER REQUIREMENTS

Run	Winter	Min. Laker Class	Icebreaker Fleet	Max. Resp. Time	Convoying Icebreaker	Channel Clearing*	Extended Nav. Season Cargo Tonnage
8	Severe	6	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	~54,800,000 Short Tons
9	Severe	6	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	12 inches/period	~55,000,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	Both the number of icebreakers and icebreaker size were reduced significantly due to channel clearing. For example in period 6, the required 9 icebreakers (2 Class D, 4 Class C, 3 Class B) operating at 49% utilization were reduced to 5 icebreakers (3 Class C, 2 Class B) operating at 79% utilization. In period 8, the required 12 icebreakers (8 Class C, 4 Class B) operating at 55% utilization were reduced to 7 icebreakers (5 Class C, 2 Class B) operating at 60% utilization.	There was no channel clearing in this task command. There was virtually no change in the number of required icebreakers with 1 Class D icebreaker in period 6, 1 Class D and 3 Class C icebreakers in period 7 and for Run 9, 1 Class D icebreaker in period 8. Average icebreaker utilization was approximately 13%.	The number of icebreakers required changed only slightly with 2 Class D icebreakers; 4 Class B icebreakers; 22 Class D and 4 Class B icebreakers; 47 Class C and 5 Class B icebreakers; 10 Class D, 2 Class B, and 2 Class C icebreakers in periods 4, 5, 6, 7, 8, and 9 respectively. Channel clearing appears to have the most effect on icebreaker utilization which was reduced from an average of 24% to 21%.	Both the number of icebreakers and icebreaker size were reduced significantly due to channel clearing. For example in period 6, 8 Class C icebreakers operating at 91% utilization were required, while only 5 Class C icebreakers operating at 86% utilization were required when channel clearing was performed. Similarly in period 7, 5 Class B icebreakers were required to operate at 6% utilization, while with channel clearing only 3 Class B icebreakers operating at 27% and 1 Class C icebreaker operating at 98% were required.
Direct Assists	The total number of direct assists decreased from 671 to 572 due to channel clearing allowing more ships to go to Sault Ste. Marie without becoming stuck.	There were 11 direct assists in both runs.	The number of direct assists decreased from 337 to 292 because fewer ships were becoming stuck in the Detroit/St. Clair Rivers.	The total number of direct assists decreased from 23 to 19.
Convoys	The total number of convoys escorted increased from 587 to 653 with channel clearing. This was due to increased icebreaker speeds which could handle more convoys consisting of fewer vessels and in periods 9 and 10, due to the use of both Class C and B icebreakers for convoying instead of only Class B icebreakers.	There were no convoys in this task command.	There were no convoys in this command because the Class 5 Lakers were restricted from operating.	The number of convoys increased from 160 to 177 indicating that the number of ships per convoy was lower due to convoys being escorted at higher speeds.
Queues	The direct assistance queues were small with a maximum of 2 ships for both cases.	The direct assistance queue was zero.	There was essentially no change in the size of the direct assistance queue with an average of 3 ships in periods 6 through 8.	The size of the convoy queue decreased slightly from an average of 3.1 in Run 8 to 2.8 in Run 9.

* Channel Clearing in the St. Marys River, Whitefish Bay, Straits of Mackinac, Detroit/St. Clair System, Welland Canal, and St. Lawrence Seaway.

TABLE 6.21

COMPARISON OF MAXIMUM RESPONSE TIME MODE WITH FIXED ICEBREAKER FLEET FOR A SEVERE WINTER[1]

Run	Winter	Min. Laker Class	Icebreaker Fleet	Min. Resp. Time	Convoying Icebreaker	Channel Clearing	Extended Nav. Season Cargo Tonnage
8	Severe	6	Max. Response Time Mode	Minimum + 12 hours	Classes C & B	None	54,800,000 Short Tons
10	Severe	6	USCG Est. Severe Winter	N.A.	Classes C & B	None	54,400,000 Short Tons

ICEBREAKER TASK COMMANDS

	TACONITE	OIL CAN	COAL SHOVEL	SEAWAY
Number of Icebreakers	The MRT Mode generated fewer icebreakers to handle the demand than were specified in the fixed fleet run (a maximum of 12 icebreakers versus a fixed fleet of 18). In addition, with the exception of periods 9 and 10, the MRT Mode generated a maximum of 4 Class B icebreakers in period 8 as compared to the 6 Class B icebreakers in the fixed fleet. In period 9 and 10, the MRT generated 12 and 11 icebreakers, of which 9 and 8 were Class B respectively, and the remaining 3 were Class C as compared to the fixed fleet of 6 Class B, 10 Class C, and 2 Class D icebreakers.	The maximum number of icebreakers required in the MRT Mode run was 4 (1 Class D and 3 Class C) operating at 13% utilization in period 7. The number of icebreakers in the fixed fleet is also 4, consisting of 3 Class C and 1 Class B icebreakers operating at 21% utilization in period 7. In addition to period 7, the MRT Mode generated only one required Class D icebreaker in period 6 to perform 3 direct assists.	For period 7, which was the most severe, the MRT Mode run generated 52 icebreakers (47 Class C and 5 Class B) operating at 27% utilization, while the fixed fleet of 17 icebreakers (12 Class C and 5 Class B) operated at 86% utilization. In period 6, the MRT Mode run generated 26 icebreakers (22 Class B and 4 Class B) operating at 24% utilization, while the fixed fleet of 17 icebreakers operated at 40% utilization. In all other periods, the number of icebreakers generated by the MRT Mode were less than the fixed fleet.	The MRT Mode run required a maximum of 8 Class C icebreakers in period 6 and 5 icebreakers in periods 7 and 8; while the fixed fleet with 3 Class C icebreakers operated at 100% utilization trying to meet the demand for convoying through the Seaway.
Direct Assists	The total number of assists was essentially the same (67 versus 66) for both runs.	There were 11 direct assists in both runs occurring in periods 6 and 7.	The total number of direct assists was 316 in Run 10 and 336 in Run 8. This increase was caused by the number of ships held up in the Seaway convoy queues, resulting in more convoys of fewer ships.	There were 23 direct assists in Run 8 and 14 in Run 10. This decrease was caused by the large number of ships held up in the convoy queues until the next period, which was considerably less severe.
Convoys	The total number of convoys escorted in the MRT Mode was 587 as compared to 621 for the fixed icebreaker fleet, indicating that fewer vessels per convoy were escorted by the fixed icebreaker fleet.	There were no convoy routes defined in this task command.	There were no convoy routes defined in this task command with the Class 5 Laker restriction.	A total of 160 convoys were escorted in Run 8 versus 131 in Run 10. This decrease was caused by the 100% utilization of the 3 Class C icebreakers causing queues of ships waiting to convoy in Run 10 as compared to the average of 6 icebreakers operating in periods 6, 7, and 8.
Queues	The direct assistance queue in the MRT Mode ranged between 0 and 2 ships over the periods. In the fixed fleet run, the average size direct assistance queue continued to grow over the periods. However, inspecting the computer printout shows that the queue was being handled; it was not growing without bound.	No significant direct assistance queues occurred.	The direct assistance queues were as high as 5 (on the average) in Run 8 but were zero in Run 10.	The convoy queues in the fixed fleet run grew excessively large, particularly in periods 7 and 8.

1. In the fixed icebreaker fleet mode, icebreakers are free to respond anywhere in the task command, while in the maximum response time mode, icebreakers may respond only in those reaches with the same home port. As a result, the fixed fleet in Taconite is utilized inefficiently because a major amount of time is spent travelling between Duluth/Superior area and the Soo.

6.4 Discussion of Production Run Results

On the following pages, tables for each of the ten (10) production runs listed in Section 6.3 present a summary of:

- Input Run Condition
- Fixed Icebreaker Fleet or MRT Generated Icebreaker Fleet by Icebreaker Class, Task Command, and Period
- Statistics for Each Icebreaker Task Command (Taconite, Oil Can, Coal Shovel, Seaway)
    - Number of Icebreakers by Class and Period
    - Number of Icebreaker Direct Assists by Class and Period
    - Number of Icebreaker Hours Associated with Direct Assistance by Period
    - Number of Icebreaker Miles Associated with Direct Assistance by Period
    - Number of Icebreaker Convoys Escorted by Class and Period
    - Number of Icebreaker Hours Associated with Convoying by Period
    - Number of Icebreaker Miles Associated with Convoying by Period
    - Size of Direct Assistance and Convoy Queues
- Extended Navigation Season Tonnages by Commodity and Route

Detailed output from each of these production runs has been provided to the U.S. Coast Guard separately as computer print-outs.

For ease of reference, the summary tables for each of the runs listed in Table 6.10 in Section 6.3 are on the following pages.

Run Number	Table Number	Page Number
1	6.22a-g	6-39 - 6-45
2	6.23a-g	6-46 - 6-52
3	6.24a-g	6-53 - 6-59
4	6.25a-g	6-60 - 6-66
5	6.26a-g	6-67 - 6-73
6	6.27a-g	6-74 - 6-80
7	6.28a-g	6-81 - 6-87
8	6.29a-g	6-88 - 6-94
9	6.30a-g	6-95 - 6-101
10	6.31a-g	6-102- 6-108

TABLE 6.22a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 1

Winter Type: Normal

Minimum Laker Class: 5

Run Mode: Fixed Icebreaker Fleet

USCG Estimated Fleet: Normal

MRT (hr): N.A.

Convoying Icebreaker Types: C,B

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	5
St. Marys River/Whitefish Bay	50,51	6-10
Straits of Mackinac	53	8
Detroit/St. Clair River System	72,73	None
Welland Canal	89	None
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDNRL, SPDNRM, SPDNRH, SHIPPRO, EAGDFIB, RCH2NR5, RCH1S, CLASS

Archived Output File Name: PRO1A

TABLE 6.22b

USCG ESTIMATED FLEET* FOR NORMAL WINTER
FOR RUN NO. 1

Home Port	Class B	Class C
Duluth	-	2
Sault Ste. Marie	2	4
St. Ignace	1	1
Port Huron, Detroit, Toledo	1	2
Escanaba	-	1
Chicago	-	1
Saginaw	-	-
Sandusky	-	1
Buffalo	1	2
Oswego	-	3
SUBTOTAL	5	17
TOTAL	22	

NOTE: Principal ports; operations limited to vessels of reasonably high capability (SHP/L > 6); 12 hrs per day per icebreaker.

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* Letter dated 8 June 1977 from Commander, Ninth Coast Guard District to the Commandant (G-O).

TABLE 6.22c

RESULTS OF RUN NO. 1

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	7-0%	7-0%	7-6%	7-102%	7-92%	7-97%	7-97%	7-101%	7-62%
Class B	3-0%	3-0%	3-5%	3-97%	3-101%	3-99%	3-100%	3-100%	3-49%
TOTAL	10-0%	10-0%	10-5%	10-100%	10-94%	10-98%	10-98%	10-100%	10-58%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	32	85	31	30	4	41	6
by Class B	-	-	3	35	128	147	96	133	10
TOTAL	-	-	35	120	159	177	100	174	16
Total Time (hr)	-	-	176	1621	1125	1118	772	1570	227
Total Miles	-	-	1703	21502	12522	11973	9557	14606	3189
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	66	113	99	104	82	79
by Class B	-	-	-	35	8	7	9	5	22
TOTAL	-	-	-	101	121	106	113	87	101
Total Time (hr)	-	-	-	1744	2045	2162	2511	1797	1710
Total Miles	-	-	-	21544	17970	20839	22638	13474	15915
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	4	10	11	6	9	1
St. Marys R. Convoy	-	-	-	27/3	24/11	15/11	7/8	15/8	18/11
Straits Convoy	-	-	-	-	-	-	2/2	-	-

NOTES:
1. Second number is average percent time utilized; values greater than 100% sometimes result because time for assists and convoys not completed during previous period are included.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.
3. In the fixed icebreaker fleet mode, an icebreaker is free to respond anywhere in the task command, while for the maximum response time mode an icebreaker may respond only in those reaches with the same home port. As a result, the fixed fleet in Taconite is utilized inefficiently because a major amount of time is spent travelling between Duluth/Superior area and the Soo.

TABLE 6.22d

RESULTS OF RUN NO. 1

FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	2-0%	2-0%	2-0%	2-23%	2-95%	2-17%	2-80%	2-6%	2-0%
Class B	-	-	-	-	-	-	-	-	-
TOTAL	2-0%	2-0%	2-0%	2-23%	2-95%	2-17%	2-80%	2-6%	2-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	8	37	6	27	2	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	8	37	6	27	2	-
Total Time (hr)	-	-	-	154	639	111	536	41	-
Total Miles	-	-	-	1935	7841	1265	6413	593	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	0	2	0	0	0	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.22e

RESULTS OF RUN NO. 1

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	5-0%	5-0%	5-1%	5-54%	5-102%	5-5%	5-0%	5-0%	5-0%
Class B	2-0%	2-0%	2-0%	2-51%	2-97%	2-5%	2-0%	2-0%	2-0%
TOTAL	7-0%	7-0%	7-1%	7-53%	7-101%	7-5%	7-0%	7-0%	7-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	1	46	77	4	-	-	-
by Class B	-	-	-	24	42	6	-	-	-
TOTAL	-	-	1	70	119	10	-	-	-
Total Time (hr)	-	-	18	1246	2365	123	-	-	-
Total Miles	-	-	208	11576	20806	1393	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	2	0	-	-	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES:
1. Second number is average percent time utilized; values greater than 100% sometimes result because time for assists and convoys not completed during previous period are included.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.
3. In the fixed icebreaker fleet mode, an icebreaker is free to respond anywhere in the task command, while for the maximum response time mode an icebreaker may respond only in those reaches with the same home port. As a result, the fixed fleet in Taconite is utilized inefficiently because a major amount of time is spent travelling between Duluth/Superior area and the Soo.

TABLE 6.22f

RESULTS OF RUN NO. 1

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	3-0%	3-0%	3-0%	3-109%	3-99%	3-97%	3-94%	3-2%	3-0%
Class B	-	-	-	-	-	-	-	-	-
TOTAL	3-0%	3-0%	3-0%	3-109%	3-99%	3-97%	3-94%	3-2%	3-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	52	45	44	32	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	52	45	44	32	-	-
Total Time (hr)	-	-	-	1099	1000	977	945	-	-
Total Miles	-	-	-	10301	8188	8846	8537	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	-	-	-	-	-
St. Lawrence Seaway Convoy	-	-	-	2/4	2/6	2/4	0/2	-	-

NOTES:
1. Second number is average percent time utilized; values greater than 100% sometimes result because time for assists and convoys not completed during previous period are included.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.
3. *In the fixed icebreaker fleet mode*, an icebreaker is free to respond anywhere in the task command, while for the maximum response time mode an icebreaker may respond only in those reaches with the same home port. As a result, the fixed fleet in Taconite is utilized inefficiently because a major amount of time is spent travelling between Duluth/Superior area and the Soo.

TABLE 6.22g

EXTENDED SEASON TONNAGE
BY ROUTE FOR RUN NO. 1

IRON ORE-LAKER

Route	Tons
1	647
2	1024
3	574
4	158
5	878
6	877
8	1406
9	1459
10	874
11	999
12	1724
13	1661
14	877
15	602
17	1193
19	879
20	476
21	283

IRON ORE-LAKER

Route	Tons
22	649
23	877
24	1023
26	599
27	438
28	606
29	1043
30	1440
32	542
33	875
34	613
35	488
37	1034
38	913
39	999
41	640
42	929
TOTAL	30299

COAL-LAKER

Route	Tons
44	1071
45	1089
46	1092
47	449
48	2862
49	1038
51	1191
53	181
54	978
56	121
57	100
58	226
59	224
60	597
61	1943
63	155
64	293
65	221
66	1357
68	201
69	201
70	439
71	607
72	2531
TOTAL	19167

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	641
78	1319
80	50
81	99
83	-
85	50
TOTAL	2159

GENERAL CARGO-SALTY

Route	Tons
87	466

BULK CARGO-SALTY

Route	Tons
88	6220
89	2621
90	708
91	327
92	445
93	606
TOTAL	10927
GRAND TOTAL	63018

Maximum Number of Vessels:

Lakers: 159
Salty General Cargo: 28
Salty Bulk: 126

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.23a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 2

Winter Type: Normal

Minimum Laker Class: 5

Run Mode: Maximum Response Time

USCG Estimated Fleet: N.A.

MRT (hr): Minimum*

Convoying Icebreaker Types: C,B

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	5
St. Marys River/Whitefish Bay	50,51	6-10
Straits of Mackinac	53	8
Detroit/St. Clair River System	72,73	None
Welland Canal	89	None
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDNRL, SPDNRM, SPDNRH, SHIPPRO, EAGDMRT, RCH2NR5, RCHIN, CLASS

Archived Output File Name: PRO2Z

* The minimum value of the maximum response time is calculated as the time required to get to the furthest point in the reach from the closest home port, at 5 mph.

TABLE 6.23b

PREDICTED ICEBREAKER FLEET BY HOME PORT AND PERIOD FOR RUN NO. 2

	CLASS D									CLASS C									CLASS B								
LOCATION	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
THUNDER BAY TC	-	-	-	4	-	-	-	1	-	-	-	-	-	3	5	-	-	-	-	-	-	-	-	-	4	-	-
Duluth	-	-	3	-	-	-	-	-	1	-	-	-	5	-	-	-	-	-	-	-	-	-	4	3	3	3	-
Presque Isle	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sault Ste. Marie	-	-	-	-	2	-	1	-	-	-	-	-	4	7	7	5	7	6	-	-	-	-	-	-	-	-	-
St. Ignace	-	-	-	-	5	3	0	-	1	-	-	-	-	-	-	2	4	-	-	-	-	-	-	-	-	-	-
TACONITE TC	-	-	4	-	7	3	2	-	2	-	-	-	9	7	7	7	11	6	-	-	-	-	4	3	3	3	-
Escanaba	-	-	-	4	16	4	14	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green Bay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chicago	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL CAN TC	-	-	-	4	16	4	14	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saginaw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Huron	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Detroit	-	-	-	5	6	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toledo	-	-	-	6	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sandusky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cleveland	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo	-	-	-	7	12	1	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
COAL SHOVEL TC	-	-	1	18	24	4	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Colborne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toronto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WELLAND TC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oswego	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alexandria Bay	-	-	-	-	-	-	-	-	-	-	-	-	5	4	6	4	1	-	-	-	-	-	-	-	-	-	-
SEAWAY TC	-	-	-	-	-	-	-	-	-	-	-	-	5	4	6	4	1	-	-	-	-	-	-	-	-	-	-
Montreal	-	-	-	-	-	-	-	-	-	-	-	-	6	5	5	3	1	-	-	-	-	-	-	0	-	0	-
Quebec	-	4	4	4	4	2	3	2	5	-	-	-	1	-	4	-	-	-	-	-	-	-	5	6	12	8	-
QUEBEC TC	-	4	4	4	4	2	3	2	5	-	-	-	7	5	9	3	1	-	-	-	-	-	5	6	12	8	-
U.S.	-	-	5	22	47	11	16	4	2	-	-	-	14	15	13	11	12	6	-	-	-	-	4	3	3	3	-

TABLE 6.23c

RESULTS OF RUN NO. 2

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	4-13%	-	7-12%	3-25%	2-10%	-	2-2%
Class C	-	-	-	9-28%	7-87%	7-83%	7-80%	11-70%	6-85%
Class B	-	-	-	-	4-33%	3-40%	3-33%	3-37%	-
TOTAL	-	-	4-13%	9-28%	18-46%	13-60%	12-56%	14-63%	8-64%
Direct Assists									
by Class D	-	-	35	-	34	28	4	-	5
by Class C	-	-	-	133	1	1	2	48	1
by Class B	-	-	-	-	144	128	107	118	-
TOTAL	-	-	35	133	179	157	113	166	6
Total Time (hr)	-	-	181	478	736	663	417	995	24
Total Miles	-	-	1379	3081	4286	3997	2943	5819	187
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	148	129	121	115	95	109
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	148	129	121	115	95	109
Total Time (hr)	-	-	-	1234	2024	1934	1848	1946	1703
Total Miles	-	-	-	9706	17309	15901	13149	12777	14428
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	-	-	-	-	-
St. Marys R. Convoy	-	-	-	23/2	23/11	17/11	9/8	12/7	16/11
Straits Convoy	-	-	-	-	-	-	3/2	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.23d

RESULTS OF RUN NO. 2

FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	4-10%	16-16%	4-11%	14-17%	4-7%	-
Class C	-	-	-	-	-	-	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	4-10%	16-16%	4-11%	14-17%	4-7%	-
Direct Assists									
by Class D	-	-	-	8	35	7	30	10	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	8	35	7	30	10	-
Total Time (hr)	-	-	-	129	850	152	811	93	-
Total Miles	-	-	-	1129	8512	1368	7531	1041	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	0	2	1	2	1	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.23e

RESULTS OF RUN NO. 2

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	1-3%	18-24%	24-26%	4-6%	-	-	-
Class C	-	-	-	-	4-37%	-	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	1-3%	18-24%	28-27%	4-6%	-	-	-
Direct Assists									
by Class D	-	-	1	68	77	10	-	-	-
by Class C	-	-	-	-	42	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	1	68	119	10	-	-	-
Total Time (hr)	-	-	10	1434	2574	78	-	-	-
Total Miles	-	-	74	8441	11305	386	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	1	1	0	-	-	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.23f

RESULTS OF RUN NO. 2

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	-	-	-	5-89%	4-91%	6-89%	4-51%	1-10%	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	5-89%	4-91%	6-89%	4-51%	1-10%	-
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	61	49	64	25	1	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	61	49	64	25	1	-
Total Time (hr)	-	-	-	1492	1223	1799	686	33	-
Total Miles	-	-	-	14210	10150	16530	5945	290	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	-	-	-	-	-
St. Lawrence Seaway Convoy	-	-	-	1/4	2/5	1/4	0/1	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.23g

EXTENDED SEASON TONNAGE

BY ROUTE FOR RUN NO. 2

IRON ORE-LAKER

Route	Tons
1	649
2	1024
3	572
4	161
5	873
6	875
8	1409
9	1457
10	876
11	1000
12	1727
13	1661
14	876
15	602
17	1193
19	881
20	476
21	283

IRON ORE-LAKER

Route	Tons
22	649
23	875
24	1023
26	601
27	438
28	606
29	1045
30	1441
32	541
33	877
34	612
35	485
37	1035
38	915
39	999
41	640
42	938
TOTAL	30315

COAL-LAKER

Route	Tons
44	1071
45	1089
46	1091
47	449
48	2866
49	1040
51	1189
53	181
54	978
56	121
57	100
58	226
59	224
60	597
61	1942
63	155
64	293
65	221
66	1357
68	201
69	201
70	439
71	607
72	2531
TOTAL	19169

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	651
78	1349
80	50
81	99
83	-
85	51
TOTAL	2200

GENERAL CARGO-SALTY

Route	Tons
87	440

BULK CARGO-SALTY

Route	Tons
88	6223
89	2620
90	707
91	331
92	445
93	604
TOTAL	10930

GRAND TOTAL 63054

Maximum Number of Vessels:

Lakers: 145
Salty General Cargo: 27
Salty Bulk: 111

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.24a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 3

Winter Type: Normal

Minimum Laker Class: 5

Run Mode: Maximum Response Time

USCG Estimated Fleet: N.A.

MRT (hr): Minimum + 12

Convoying Icebreaker Types: C,B

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	5
St. Marys River/Whitefish Bay	50,51	6-10
Straits of Mackinac	53	8
Detroit/St. Clair River System	72,73	None
Welland Canal	89	None
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDNRL, SPDNRM, SPDNRH, SHIPPRO, EAGDMRT, RCH2NR5, RCH1S, CLASS

Archived Output File Name: PRO3Z

TABLE 6.24b

PREDICTED ICEBREAKER FLEET BY HOME PORT AND PERIOD FOR RUN NO. 3

LOCATION	CLASS D									CLASS C									CLASS B								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
THUNDER BAY TC	-	-	-	3	-	-	-	1	-	-	-	-	-	4	7	-	-	-	-	-	-	-	-	-	-	-	-
Duluth	-	-	5	-	-	-	-	-	1	-	-	-	2	-	-	-	-	-	-	-	-	-	4	3	5	6	-
Presque Isle	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sault Ste. Marie	-	-	-	-	-	-	1	-	-	-	-	-	4	6	7	7	5	5	-	-	-	-	-	-	-	-	-
St. Ignace	-	-	-	-	3	2	1	-	1	-	-	-	-	-	-	2	5	-	-	-	-	-	-	-	-	-	-
TACONITE TC	-	-	6	-	3	2	3	-	2	-	-	-	6	6	7	9	10	5	-	-	-	-	4	3	5	6	-
Escanaba	-	-	-	4	15	4	16	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green Bay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chicago	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL CAN TC	-	-	-	4	15	4	16	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saginaw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Huron	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Detroit	-	-	-	6	7	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toledo	-	-	-	6	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sandusky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cleveland	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo	-	-	-	7	12	1	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-
COAL SHOVEL TC	-	-	-	20	25	5	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Colborne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toronto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WELLAND TC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oswego	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alexandria Bay	-	-	-	-	-	-	-	-	-	-	-	-	5	4	4	3	1	-	-	-	-	-	-	-	-	-	-
SEAWAY TC	-	-	-	-	-	-	-	-	-	-	-	-	5	4	4	3	1	-	-	-	-	-	-	-	-	-	-
Montreal	-	-	-	-	-	-	-	-	-	-	-	-	5	4	4	3	1	-	-	-	-	-	-	-	-	-	-
Quebec	-	3	4	4	3	2	3	2	6	-	-	-	1	3	6	-	-	-	-	-	-	-	4	6	9	9	-
QUEBEC TC	-	3	4	4	3	2	3	2	6	-	-	-	6	7	10	3	1	-	-	-	-	-	4	6	9	9	-
U.S.	-	-	6	24	43	11	19	3	2	-	-	-	11	15	11	12	11	5	-	-	-	-	4	3	5	6	-

TABLE 6.24c

RESULTS OF RUN NO. 3

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	6-9%	-	3-24%	2-39%	3-8%	-	2-3%
Class C	-	-	-	6-8%	6-91%	7-83%	9-61%	10-63%	5-96%
Class B	-	-	-	-	4-34%	3-40%	5-19%	6-19%	-
TOTAL	-	-	6-9%	6-8%	13-58%	12-65%	17-39%	16-46%	7-69%
Direct Assists									
by Class D	-	-	35	-	28	30	5	-	6
by Class C	-	-	-	129	4	1	2	50	1
by Class B	-	-	-	-	144	130	105	122	-
TOTAL	-	-	35	129	176	161	112	172	7
Total Time (hr)	-	-	181	497	741	674	425	1024	25
Total Miles	-	-	1379	3637	4737	3893	2920	5868	205
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	149	123	120	110	87	110
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	149	123	120	110	87	110
Total Time (hr)	-	-	-	1179	1777	1932	1821	1456	1596
Total Miles	-	-	-	9200	14951	15889	12967	9174	13339
Avg. Size of Queues[2]									
Direct Assistance	-	-	1	1	1	0	0	1	0
St. Marys R. Convoy	-	-	-	23/2	24/12	17/13	9/9	14/10	17/15
Straits Convoy	-	-	-	-	-	-	3/3	-	-

NOTES: 1. Second number is average percent time utilized.

2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are <u>not</u> waiting.

TABLE 6.24d

RESULTS OF RUN NO. 3

FOR OIL CAN TASK COMMAND

ITEM	2	3	4	5	6	7	8	9	10
					Period				
Number of Icebreakers[1]									
Class D	-	-	-	4-10%	15-16%	4-10%	16-15%	3-7%	-
Class C	-	-	-	-	-	-	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	4-10%	15-16%	4-10%	16-15%	3-7%	-
Direct Assists									
by Class D	-	-	-	8	33	6	30	9	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	8	33	6	30	9	-
Total Time (hr)	-	-	-	129	812	134	789	72	-
Total Miles	-	-	-	1129	8101	1212	7288	777	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	1	2	1	3	1	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.24e

RESULTS OF RUN NO. 3

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	20-21%	25-25%	5-7%	-	-	-
Class C	-	-	-	-	5-29%	-	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	20-21%	30-26%	5-7%	-	-	-
Direct Assists									
by Class D	-	-	-	68	78	11	-	-	-
by Class C	-	-	-	-	41	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	68	119	11	-	-	-
Total Time (hr)	-	-	-	1392	2610	120	-	-	-
Total Miles	-	-	-	8173	11434	682	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	2	3	0	-	-	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.24f

RESULTS OF RUN NO. 3

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	-	-	-	5-82%	4-76%	4-87%	3-72%	1-10%	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	5-82%	4-76%	4-87%	3-72%	1-10%	-
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	60	46	52	26	1	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	60	46	52	26	1	-
Total Time (hr)	-	-	-	1382	1019	1172	722	33	-
Total Miles	-	-	-	13050	8265	10440	6235	290	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	-	-	-	-	-
St. Lawrence Seaway Convoy	-	-	-	1/4	5/6	2/6	0/2	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound ; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.24g

EXTENDED SEASON TONNAGE

BY ROUTE FOR RUN NO. 3

IRON ORE-LAKER

Route	Tons
1	649
2	1023
3	571
4	161
5	873
6	878
8	1409
9	1455
10	876
11	999
12	1726
13	1655
14	878
15	602
17	1191
19	877
20	476
21	283

IRON ORE-LAKER

Route	Tons
22	649
23	877
24	1025
26	601
27	437
28	605
29	1044
30	1438
32	541
33	878
34	612
35	494
37	1035
38	915
39	999
41	641
42	934
TOTAL	30307

COAL-LAKER

Route	Tons
44	1070
45	1089
46	1091
47	449
48	2866
49	1038
51	1192
53	181
54	978
56	121
57	100
58	226
59	224
60	597
61	1890
63	155
64	293
65	221
66	1357
68	201
69	201
70	438
71	606
72	2531
TOTAL	19115

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	651
78	1349
80	50
81	99
83	-
85	50
TOTAL	2199

GENERAL CARGO-SALTY

Route	Tons
87	446

BULK CARGO-SALTY

Route	Tons
88	6224
89	2632
90	708
91	330
92	445
93	603
TOTAL	10942
GRAND TOTAL	63009

Maximum Number of Vessels:

Lakers: 150
Salty General Cargo: 28
Salty Bulk: 114

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.25a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 4

Winter Type: Normal

Minimum Laker Class: 5

Run Mode: Fixed Icebreaker Fleet

USCG Estimated Fleet: Normal

MRT (hr): N.A.

Convoying Icebreaker Types: C,B

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000 + 20%

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	5
St. Marys River/Whitefish Bay	50,51	6-10
Straits of Mackinac	53	8
Detroit/St. Clair River System	72,73	None
Welland Canal	89	None
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDNRL, SPDNRM, SPDNRH, SHIPP20, EAGDFIB, RCH2NR5, RCH1S, CLASS

Archived Output File Name: PRO4A

TABLE 6.25b

USCG ESTIMATED FLEET* FOR NORMAL WINTER
FOR RUN NO. 4

Home Port	Class B	Class C
Duluth	-	2
Sault Ste. Marie	2	4
St. Ignace	1	1
Port Huron, Detroit, Toledo	1	2
Escanaba	-	1
Chicago	-	1
Saginaw	-	-
Sandusky	-	1
Buffalo	1	2
Oswego	-	3
SUBTOTAL	5	17
TOTAL	22	

NOTE: Principal ports; operations limited to vessels of reasonably high capability (SHP/L > 6); 12 hrs per day per icebreaker.

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* Letter dated 8 June 1977 from Commander, Ninth Coast Guard District to the Commandant (G-O).

TABLE 6.25c

RESULTS OF RUN NO. 4

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	7-	7-	7-6%	7-99%	7-98%	7-101%	7-98%	7-101%	7-84%
Class B	3-	3-	3-16%	3-96%	3-98%	3-100%	3-102%	3-102%	3-62%
TOTAL	10-	10-	10-9%	10-98%	10-98%	10-100%	10-99%	10-101%	10-77%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	36	92	38	39	10	51	12
by Class B	-	-	5	43	155	180	127	116	13
TOTAL	-	-	41	135	193	219	137	167	25
Total Time (hr)	-	-	315	1663	1197	1227	818	1783	411
Total Miles	-	-	3855	21760	12517	12140	8884	16302	5903
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	75	134	126	124	80	100
by Class B	-	-	-	30	9	8	11	7	26
TOTAL	-	-	-	105	143	134	135	87	126
Total Time (hr)	-	-	-	1637	2093	2142	2514	1613	2187
Total Miles	-	-	-	20048	19501	19442	21267	12343	21168
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	5	14	12	8	12	3
St. Marys R. Convoy	-	-	-	33/9	34/18	20/13	10/8	18/11	23/23
Straits Convoy	-	-	-	-	-	-	3/2	1/0	-

NOTES:
1. Second number is average percent time utilized; values greater than 100% sometimes result because time for assists and convoys not completed during previous period are included.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.
3. In the fixed icebreaker fleet mode, an icebreaker is free to respond anywhere in the task command, while for the maximum response time mode an icebreaker may respond only in those reaches with the same home port. As a result, the fixed fleet in Taconite is utilized inefficiently because a major amount of time is spent travelling between Duluth/Superior area and the Soo.

TABLE 6.25d
RESULTS OF RUN NO. 4
FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	2-0%	2-0%	2-0%	2-19%	2-95%	2-26%	2-84%	2-8%	2-0%
Class B	-	-	-	-	-	-	-	-	-
TOTAL	2-0%	2-0%	2-0%	2-19%	2-95%	2-26%	2-84%	2-8%	2-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	10	40	8	27	3	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	10	40	8	27	3	-
Total Time (hr)	-	-	-	127	639	173	563	53	-
Total Miles	-	-	-	1394	7697	2162	6934	764	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	0	1	0	1	0	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.25e

RESULTS OF RUN NO. 4

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	5-0%	5-0%	5-2%	5-64%	5-102%	5-14%	5-0%	5-0%	5-0%
Class B	2-0%	2-0%	2-0%	2-67%	2-101%	2-11%	2-1%	2-0%	2-0%
TOTAL	7-0%	7-0%	7-1%	7-65%	7-102%	7-13%	7-0%	7-0%	7-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	2	53	77	14	-	-	-
by Class B	-	-	-	28	49	11	1	-	-
TOTAL	-	-	2	81	126	25	1	-	-
Total Time (hr)	-	-	35	1525	2392	314	4	-	-
Total Miles	-	-	416	14410	21220	3632	44	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	6	1	1	-	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized; values greater than 100% sometimes result because time for assists and convoys not completed during previous period are included.

2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.25f

RESULTS OF RUN NO. 4

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	3-0%	3-0%	3-0%	3-107%	3-103%	3-100%	3-87%	3-4%	3-0%
Class B	-	-	-	-	-	-	-	-	-
TOTAL	3-0%	3-0%	3-0%	3-107%	3-103%	3-100%	3-87%	3-4%	3-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	54	50	50	33	1	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	54	50	50	33	1	-
Total Time (hr)	-	-	-	1076	1041	1009	871	38	-
Total Miles	-	-	-	9927	8355	8790	7738	412	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	-	-	-	-	-
St. Lawrence Seaway Convoy	-	-	-	5/5	5/10	6/12	1/3	-	-

NOTES: 1. Second number is average percent time utilized; values greater than 100% sometimes result because time for assists and convoys not completed during previous period are included.

2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.25g

EXTENDED SEASON TONNAGE
BY ROUTE FOR RUN NO. 4

IRON ORE-LAKER

Route	Tons
1	872
2	1141
3	632
4	210
5	1017
6	1013
8	1687
9	1802
10	1024
11	1041
12	2047
13	1919
14	1028
15	748
17	1436
19	1030
20	576
21	299

IRON ORE-LAKER

Route	Tons
22	814
23	1071
24	1140
26	648
27	548
28	648
29	1310
30	1742
32	761
33	1019
34	718
35	589
37	1271
38	1040
39	1070
41	768
42	1109
TOTAL	35734

COAL-LAKER

Route	Tons
44	1309
45	1322
46	1326
47	587
48	3330
49	1284
51	1406
53	226
54	1179
56	141
57	141
58	283
59	262
60	739
61	2327
63	181
64	372
65	262
66	1640
68	242
69	222
70	527
71	744
72	3045
TOTAL	23097

GRAIN-LAKER

Route	Tons
74	41
75	25
76	-
77	782
78	1483
80	50
81	123
83	25
85	74
TOTAL	2603

GENERAL CARGO-SALTY

Route	Tons
87	548

BULK CARGO-SALTY

Route	Tons
88	7201
89	3178
90	868
91	373
92	526
93	739
TOTAL	12885

GRAND TOTAL 74867

Maximum Number of Vessels:

Lakers: 198
Salty General Cargo: 35
Salty Bulk: 157

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.26a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 5

Winter Type: Severe

Minimum Laker Class: 5

Run Mode: Maximum Response Time

USCG Estimated Fleet: N.A.

MRT (hr): Minimum + 12

Convoying Icebreaker Types: B only

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	4
St. Marys River/Whitefish Bay	50,51	5-10
Straits of Mackinac	53	5-10
Detroit/St. Clair River System	72,73	5-7
Welland Canal	89	5-7
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDSVL, SPDSVM, SPDSVH, SHIPPRO, EAGDMRT, RCH2SV5, RCH1S, CLASSNC

Archived Output File Name: PRO5A

TABLE 6.26b

PREDICTED ICEBREAKER FLEET BY HOME PORT AND PERIOD FOR RUN NO. 5

LOCATION	CLASS D									CLASS C									CLASS B								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
THUNDER BAY TC	-	-	1	2	-	-	-	2	3	-	-	-	-	6	-	6	-	-	-	-	-	-	-	8	-	-	-
Duluth	-	-	3	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	4	4	2	4	4
Presque Isle	-	-	-	-	-	29	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sault Ste. Marie	-	-	-	2	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	3	3	4	3	3	3	3
St. Ignace	-	-	-	-	-	-	2	1	2	-	-	-	-	-	-	-	-	-	-	-	-	2	2	2	2	2	1
TACONITE TC	-	-	3	2	-	29	15	1	2	-	-	-	4	-	1	-	-	-	-	-	3	5	10	9	7	9	8
Escanaba	-	2	3	2	1	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	4	-	-	-
Green Bay	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chicago	-	-	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL CAN TC	-	2	8	3	2	-	-	-	-	-	-	-	-	4	3	-	-	-	-	-	-	-	-	4	-	-	-
Saginaw	-	-	-	29	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Huron	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	2	1	-	-
Detroit	-	-	-	2	8	-	2	-	-	-	-	-	-	-	10	-	-	-	-	-	-	3	3	2	1	-	-
Toledo	-	-	-	1	20	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-
Sandusky	-	2	1	4	6	3	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Cleveland	-	1	-	4	3	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo	-	-	2	-	1	1	12	2	1	-	-	-	-	-	24	-	1	-	-	-	-	4	6	6	2	-	-
COAL SHOVEL TC	-	3	3	40	44	4	14	2	1	-	-	-	-	-	43	-	1	-	-	-	-	9	11	10	4	-	-
Port Colborne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	4	1	-	-
Toronto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WELLAND TC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	4	1	-	-
Oswego	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alexandria Bay	-	-	1	1	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	3	4	5	3	-	-
SEAWAY TC	-	-	1	1	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	3	4	5	3	-	-
Montreal	-	-	1	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	4	6	5	4	2	-
Quebec	-	3	4	5	5	2	3	5	-	-	-	-	-	-	4	6	-	-	-	-	-	-	2	5	-	-	-
QUEBEC TC	-	3	5	5	5	2	3	5	3	-	-	-	-	-	4	6	-	-	-	-	-	4	8	10	4	2	-
	-	5	15	46	46	33	30	3	3	-	-	-	4	5	47	-	1	-	-	-	3	17	25	28	14	9	8

TABLE 6.26c
RESULTS OF RUN NO. 5
FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	3-23%	2-13%	-	29-34%	15-09%	1-28%	2-22%
Class C	-	-	-	4-76%	-	1-20%	-	-	-
Class B	-	-	3-83%	5-60%	10-53%	9-56%	7-66%	9-51%	8-61%
TOTAL	-	-	6-53%	11-57%	10-53%	39-39%	22-27%	10-49%	10-53%
Direct Assists									
by Class D	-	-	39	7	-	59	34	15	23
by Class C	-	-	-	122	-	5	-	-	-
by Class B	-	-	-	3	154	154	135	147	139
TOTAL	-	-	39	132	154	218	169	162	162
Total Time (hr)	-	-	235	1131	637	4033	1100	769	803
Total Miles	-	-	944	4451	3797	19471	7410	4322	4894
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	96	78	95	84	76	72	80
TOTAL	-	-	96	78	95	84	76	72	80
Total Time (hr)	-	-	840	968	1161	1063	927	877	978
Total Miles	-	-	6670	7870	10372	9557	7773	7847	8853
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	1	1	4	4	1	1
St. Marys R. Convoy	-	-	32/1	21/18	19/24	14/19	13/11	15/13	16/14
Straits Convoy	-	-	-	4/6	5/8	4/8	4/6	2/3	4/4

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.26d

RESULTS OF RUN NO. 5

FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	2-11%	8-10%	3-21%	2-16%	-	-	-	-
Class C	-	-	-	-	4-26%	3-15%	-	-	-
Class B	-	-	-	-	-	4-13%	-	-	-
TOTAL	-	2-11%	8-10%	3-21%	6-23%	7-14%	-	-	-
Direct Assists									
by Class D	-	9	21	12	3	-	-	-	-
by Class C	-	-	-	-	29	6	-	-	-
by Class B	-	-	-	-	-	23	-	-	-
TOTAL	-	9	21	12	32	29	-	-	-
Total Time (hr)	-	77	252	208	454	326	-	-	-
Total Miles	-	312	2228	1022	1524	2208	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	0	1	0	0	0	-	-	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.26e

RESULTS OF RUN NO. 5

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	3-10%	3-19%	40-34%	44-36%	4-58%	14-22%	2-13%	1-04%
Class C	-	-	-	-	-	43-32%	-	1-29%	-
Class B	-	-	-	9-45%	11-51%	10-42%	4-15%	0	-
TOTAL	-	3-10%	3-19%	49-36%	55-39%	57-36%	18-21%	3-18%	1-04%
Direct Assists									
by Class D	-	10	20	92	119	8	22	2	4
by Class C	-	-	-	-	-	123	-	22	-
by Class B	-	-	-	54	47	34	26	-	-
TOTAL	-	10	20	146	166	165	48	24	4
Total Time (hr)	-	98	190	5263	6304	6169	1250	183	13
Total Miles	-	731	688	26331	32468	30057	6027	1047	60
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	51	66	57	3	-	-
TOTAL	-	-	-	51	66	57	3	-	-
Total Time (hr)	-	-	-	660	854	695	50	-	-
Total Miles	-	-	-	5463	6926	5560	389	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	0	0	6	4	5	2	0	0
Detroit/St. Clair Convoy	-	-	-	14/15	17/13	14/11	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound ; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.26f

RESULTS OF RUN NO. 5

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	1-25%	1-32%	-	-	1-24%	-	-
Class C	-	-	-	-	1-36%	-	-	-	-
Class B	-	-	-	3-77%	4-85%	5-57%	3-62%	-	-
TOTAL	-	-	1-25%	4-66%	5-75%	5-57%	4-52%	-	-
Direct Assists									
by Class D	-	-	2	4	-	-	6	-	-
by Class C	-	-	-	-	9	-	-	-	-
by Class B	-	-	-	-	6	13	2	-	-
TOTAL	-	-	2	4	15	13	8	-	-
Total Time (hr)	-	-	83	106	201	144	103	-	-
Total Miles	-	-	519	458	1065	888	576	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	32	44	32	25	-	-
TOTAL	-	-	-	32	44	32	25	-	-
Total Time (hr)	-	-	-	778	1060	809	601	-	-
Total Miles	-	-	-	7395	10095	7575	5685	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	0	0	0	-	-
St. Lawrence Seaway Convoy	-	-	-	1/3	3/5	1/3	0/4	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.26g

EXTENDED SEASON TONNAGE
BY ROUTE FOR RUN NO. 5

IRON ORE-LAKER		IRON ORE-LAKER		COAL-LAKER		GRAIN-LAKER	
Route	Tons	Route	Tons	Route	Tons	Route	Tons
1	645	22	649	44	1072	74	-
2	1026	23	874	45	1089	75	-
3	569	24	1023	46	1088	76	-
4	161	26	602	47	449	77	641
5	872	27	438	48	2856	78	1372
6	876	28	605	49	1039	80	50
8	1399	29	1041	51	1187	81	100
9	1429	30	1445	53	181	83	-
10	872	32	542	54	978	85	50
11	995	33	859	56	121	TOTAL	2213
12	1721	34	610	57	100		
13	1643	35	489	58	226		
14	863	37	1034	59	224		
15	602	38	912	60	594		
17	1160	39	998	61	1890		
19	869	41	628	63	155		
20	475	42	937	64	293		
21	283	TOTAL	30146	65	221		
				66	1357		
				68	201		
				69	201		
				70	427		
				71	607		
				72	2532		
				TOTAL	19089		

GENERAL CARGO-SALTY	
Route	Tons
87	455

BULK CARGO-SALTY	
Route	Tons
88	6226
89	2639
90	710
91	331
92	444
93	606
TOTAL	10956
GRAND TOTAL	62859

Maximum Number of Vessels:

Lakers: 209
Salty General Cargo: 30
Salty Bulk: 129

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.27a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 6

Winter Type: Normal

Minimum Laker Class: 5

Run Mode: Maximum Response Time

USCG Estimated Fleet: N.A.

MRT (hr): Minimum + 12

Convoying Icebreaker Types: No Convoys

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	-
St. Marys River/Whitefish Bay	50,51	-
Straits of Mackinac	53	-
Detroit/St. Clair River System	72,73	-
Welland Canal	89	-
U.S. St. Lawrence Seaway	95	-
Canadian St. Lawrence Seaway	96	-

Data Files Used: SPDNRL, SPDNRM, SPDNRH, SHIPPRO, EAGDMRT, RCH2NC, RCH1S, CLASS

Archived Output File Name: PRO6A

TABLE 6.27b

PREDICTED ICEBREAKER FLEET BY HOME PORT AND PERIOD FOR RUN NO. 6

LOCATION	CLASS D									CLASS C									CLASS B								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
THUNDER BAY TC	-	-	-	3	-	-	-	1	-	-	-	-	-	3	4	-	-	-	-	-	-	-	-	-	4	-	-
Duluth	-	-	5	-	-	-	-	-	1	-	-	-	10	-	-	-	-	-	-	-	-	-	11	9	10	12	-
Presque Isle	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sault Ste. Marie	-	-	-	7	9	13	8	-	8	-	-	-	-	-	-	8	14	-	-	-	-	-	-	-	-	-	-
St. Ignace	-	-	-	-	3	4	7	-	2	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-
TACONITE TC	-	-	6	7	12	17	16	-	11	-	-	-	10	-	-	8	24	-	-	-	-	-	11	9	10	12	-
Escanaba	-	-	-	4	15	4	13	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green Bay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chicago	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL CAN TC	-	-	-	4	15	4	13	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saginaw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Huron	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Detroit	-	-	-	5	6	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toledo	-	-	-	6	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sandusky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cleveland	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo	-	-	-	7	11	1	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-
COAL SHOVEL TC	-	-	-	19	21	3	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Colborne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toronto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WELLAND TC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oswego	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alexandria Bay	-	-	-	-	3	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SEAWAY TC	-	-	-	-	3	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Montreal	-	-	-	-	2	4	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Quebec	-	3	4	5	3	2	3	2	4	-	-	-	4	3	5	-	-	-	-	-	-	-	6	5	15	11	-
QUEBEC TC	-	3	4	5	5	6	3	2	4	-	-	-	4	3	5	2	-	-	-	-	-	-	6	5	15	11	-
U.S.	-	-	6	30	51	28	30	2	11	-	-	-	10	5	-	8	24	-	-	-	-	-	11	9	10	12	-

TABLE 6.27c

RESULTS OF RUN NO. 6

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	6-9%	7-44%	12-48%	17-38%	16-44%	-	11-37%
Class C	-	-	-	10-13%	-	-	8-54%	24-44%	-
Class B	-	-	-	-	11-11%	9-13%	10-9%	12-10%	-
TOTAL	-	-	6-9%	17-26%	23-31%	26-29%	34-36%	36-33%	11-37%
Direct Assists									
by Class D	-	-	35	83	117	123	79	-	91
by Class C	-	-	-	132	-	-	74	190	-
by Class B	-	-	-	-	137	135	100	126	-
TOTAL	-	-	35	215	254	258	253	316	91
Total Time (hr)	-	-	181	1470	2364	2554	4123	3935	1431
Total Miles	-	-	1379	7610	12427	12535	16628	20611	8446
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	1	2	2	1	2	2	1
St. Marys R. Convoy	-	-	-	-	-	-	-	-	-
Straits Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.27d
RESULTS OF RUN NO. 6
FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	4-10%	15-17%	4-10%	13-17%	2-8%	-
Class C	-	-	-	-	-	-	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	4-10%	15-17%	4-10%	13-17%	2-8%	-
Direct Assists									
by Class D	-	-	-	8	35	6	28	8	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	8	35	6	28	8	-
Total Time (hr)	-	-	-	129	832	128	730	53	-
Total Miles	-	-	-	1129	8320	1164	6811	537	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	1	3	1	2	0	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.27e

RESULTS OF RUN NO. 6

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	19-21%	21-30%	3-10%	-	-	-
Class C	-	-	-	-	5-29%	-	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	19-21%	26-29%	3-10%	-	-	-
Direct Assists									
by Class D	-	-	-	65	79	8	-	-	-
by Class C	-	-	-	-	41	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	65	120	8	-	-	-
Total Time (hr)	-	-	-	1350	2568	97	-	-	-
Total Miles	-	-	-	7961	11242	554	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	1	2	0	-	-	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.27f

RESULTS OF RUN NO. 6

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	3-23%	4-12%	1-43%	-	-
Class C	-	-	-	-	-	-	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	3-23%	4-12%	1-43%	-	-
Direct Assists									
by Class D	-	-	-	-	6	6	4	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	6	6	4	-	-
Total Time (hr)	-	-	-	-	229	158	143	-	-
Total Miles	-	-	-	-	1305	1160	1015	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	0	1	0	-	-
St. Lawrence Seaway Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound ; DA Queues indicate vessels which are waiting; while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.27g

EXTENDED SEASON TONNAGE

BY ROUTE FOR RUN NO. 6

IRON ORE-LAKER

Route	Tons
1	647
2	1027
3	572
4	162
5	873
6	876
8	1408
9	1484
10	878
11	1000
12	1731
13	1660
14	878
15	605
17	1191
19	881
20	476
21	283

IRON ORE-LAKER

Route	Tons
22	649
23	875
24	1026
26	601
27	438
28	605
29	1044
30	1443
32	559
33	878
34	613
35	497
37	1035
38	915
39	999
41	641
42	934
TOTAL	30394

COAL-LAKER

Route	Tons
44	1081
45	1089
46	1092
47	448
48	2879
49	1040
51	1190
53	190
54	978
56	121
57	100
58	226
59	224
60	597
61	1942
63	155
64	293
65	221
66	1357
68	201
69	201
70	439
71	606
72	2531
TOTAL	19201

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	652
78	1350
80	50
81	99
83	-
85	50
TOTAL	2201

GENERAL CARGO-SALTY

Route	Tons
87	430

BULK CARGO-SALTY

Route	Tons
88	6265
89	2644
90	708
91	330
92	443
93	602
TOTAL	10992
GRAND TOTAL	63198

Maximum Number of Vessels:

Lakers: 153
Salty General Cargo: 26
Salty Bulk: 100

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.28a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 7

Winter Type: Severe

Minimum Laker Class: 5

Run Mode: Maximum Response Time

USCG Estimated Fleet: N.A.

MRT (hr): Minimum + 12

Convoying Icebreaker Types: C,B

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	4
St. Marys River/Whitefish Bay	50,51	5-10
Straits of Mackinac	53	5-10
Detroit/St. Clair River System	72,73	5-7
Welland Canal	89	5-7
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDSVL, SPDSVM, SPDSVH, SHIPPRO, EAGDMRT, RCH25V5, RCH1S, CLASS

Archived Output File Name: PRO7A

TABLE 6.28b

PREDICTED ICEBREAKER FLEET BY HOME PORT AND PERIOD FOR RUN NO. 7

LOCATION	CLASS D									CLASS C									CLASS B								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
THUNDER BAY TC	-	-	1	2	-	-	-	-	3	-	-	-	-	3	-	5	-	-	-	-	-	-	-	7	-	-	-
Duluth	-	-	3	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	4	3	2	4	5
Presque Isle	-	-	-	-	-	27	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sault Ste. Marie	-	-	-	4	-	-	1	-	-	-	-	4	6	7	8	8	-	-	-	-	-	-	-	-	-	3	3
St. Ignace	-	-	-	-	-	-	1	2	7	-	-	-	2	2	3	4	3	3	-	-	-	-	-	-	-	-	-
TACONITE TC	-	-	3	4	-	27	15	2	7	-	-	4	13	9	11	12	3	3	-	-	-	-	4	3	2	7	8
Escanaba	-	2	3	2	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	4	-	-	-
Green Bay	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chicago	-	-	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL CAN TC	-	2	8	3	1	-	-	-	-	-	-	-	-	3	3	-	-	-	-	-	-	-	-	4	-	-	-
Saginaw	-	-	-	30	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Huron	-	-	-	-	-	-	-	-	-	-	-	-	3	3	3	3	-	-	-	-	-	-	-	-	-	-	-
Detroit	-	-	-	4	8	-	1	-	-	-	-	-	4	4	9	1	-	-	-	-	-	-	-	-	-	-	-
Toledo	-	-	-	1	19	-	1	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-
Sandusky	-	2	1	3	5	2	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Cleveland	-	1	-	4	3	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo	-	-	1	-	1	1	14	3	1	-	-	-	-	-	19	-	4	-	-	-	-	4	5	5	2	-	-
COAL SHOVEL TC	-	3	2	42	42	3	16	3	1	-	-	-	7	7	42	4	4	-	-	-	-	4	5	5	2	-	-
Port Colborne	-	-	-	-	-	-	-	-	-	-	-	-	3	5	-	3	-	-	-	-	-	-	-	3	-	-	-
Toronto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WELLAND TC	-	-	-	-	-	-	-	-	-	-	-	-	3	5	-	3	-	-	-	-	-	-	-	3	-	-	-
Oswego	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alexandria Bay	-	-	1	1	-	-	1	-	-	-	-	-	5	11	-	-	-	-	-	-	-	-	-	4	2	-	-
SEAWAY TC	-	-	1	1	-	-	1	-	-	-	-	-	5	11	-	-	-	-	-	-	-	-	-	4	2	-	-
Montreal	-	-	1	-	-	-	-	-	2	-	-	-	7	-	-	-	-	-	-	-	-	-	6	6	5	2	-
Quebec	-	3	4	5	5	2	3	7	-	-	-	-	-	-	3	6	-	-	-	-	-	-	1	3	1	-	-
QUEBEC TC	-	3	5	5	5	2	3	7	2	-	-	-	7	-	3	6	-	-	-	-	-	-	7	9	6	2	-
U.S.	-	5	14	50	43	30	32	5	8	-	-	4	25	30	56	16	7	3	-	-	-	4	9	16	6	7	8

TABLE 6.28c

RESULTS OF RUN NO. 7

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	3-24%	4-10%	-	27-34%	15-9%	2-19%	7-10%
Class C	-	-	4-89%	13-66%	9-86%	11-82%	12-70%	3-57%	3-54%
Class B	-	-	-	-	4-44%	3-55%	2-87%	7-55%	8-52%
TOTAL	-	-	7-61%	17-53%	13-73%	41-49%	29-40%	12-50%	18-36%
Direct Assists									
by Class D	-	-	40	10	-	57	32	19	34
by Class C	-	-	-	120	4	28	13	5	-
by Class B	-	-	-	-	148	127	130	132	133
TOTAL	-	-	40	130	152	212	175	156	167
Total Time (hr)	-	-	241	1102	658	3914	1196	788	821
Total Miles	-	-	955	3966	3825	19073	7681	4174	4234
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	146	146	177	158	129	38	42
by Class B	-	-	-	-	-	-	-	46	55
TOTAL	-	-	146	146	177	158	129	84	97
Total Time (hr)	-	-	1188	1914	2522	2786	2680	1212	1349
Total Miles	-	-	9292	16060	18276	17024	14442	8608	9899
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	1	4	5	0	1
St. Marys R. Convoy	-	-	31/2	20/19	17/24	14/18	15/12	15/14	17/13
Straits Convoy	-	-	-	5/6	3/6	5/6	4/5	2/4	3/4

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound.; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.28d

RESULTS OF RUN NO. /

FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	2-11%	8-11%	3-23%	1-24%	-	-	-	-
Class C	-	-	-	-	3-34%	3-15%	-	-	-
Class B	-	-	-	-	-	4-13%	-	-	-
TOTAL	-	2-11%	8-11%	3-23%	4-32%	7-14%	-	-	-
Direct Assists									
by Class D	-	9	21	12	3	-	-	-	-
by Class C	-	-	-	-	29	6	-	-	-
by Class B	-	-	-	-	-	22	-	-	-
TOTAL	-	9	21	12	32	28	-	-	-
Total Time (hr)	-	77	286	230	427	320	-	-	-
Total Miles	-	312	2263	1123	1376	2160	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	0	1	0	0	1	-	-	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.28e

RESULTS OF RUN NO. 7

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	3-10%	2-29%	42-35%	42-36%	3-78%	16-21%	3-13%	1-4%
Class C	-	-	-	7-58%	7-80%	42-44%	4-12%	4-7%	-
Class B	-	-	-	4-36%	5-58%	5-38%	2-24%	-	-
TOTAL	-	3-10%	2-29%	52-38%	54-44%	50-45%	22-20%	7-9%	1-4%
Direct Assists									
by Class D	-	10	20	99	117	7	24	3	4
by Class C	-	-	-	4	2	120	-	22	-
by Class B	-	-	-	42	46	27	26	-	-
TOTAL	-	10	20	145	165	154	50	25	4
Total Time (hr)	-	99	192	5479	6143	5629	1317	220	13
Total Miles	-	731	702	26597	31507	26817	6342	1284	60
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	101	126	111	9	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	101	126	111	9	-	-
Total Time (hr)	-	-	-	1277	1791	1934	143	-	-
Total Miles	-	-	-	10283	13467	13377	1121	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	0	0	5	4	5	2	1	0
Detroit/St. Clair Convoy	-	-	-	15/14	15/15	12/15	-	-	-

NOTES: 1. Second number is average percent time utilized.

2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established at ETA at convoy points and in general are not waiting.

TABLE 6.28f

RESULTS OF RUN NO. 7

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
<u>Number of Icebreakers</u>[1]									
Class D	-	-	1-25%	1-32%	-	-	1-28%	-	-
Class C	-	-	-	5-84%	11-71%	-	-	-	-
Class B	-	-	-	-	-	4-71%	2-82%	-	-
TOTAL	-	-	1-25%	6-75%	11-71%	4-71%	3-64%	-	-
<u>Direct Assists</u>									
by Class D	-	-	2	4	-	-	7	-	-
by Class C	-	-	-	-	12	-	-	-	-
by Class B	-	-	-	-	-	15	-	-	-
TOTAL	-	-	2	4	12	15	7	-	-
Total Time (hr)	-	-	83	106	224	175	94	-	-
Total Miles	-	-	519	458	972	1104	408	-	-
<u>Convoys Escorted</u>									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	47	54	-	-	-	-
by Class B	-	-	-	-	-	31	22	-	-
TOTAL	-	-	-	47	54	31	22	-	-
Total Time (hr)	-	-	-	1403	2415	920	549	-	-
Total Miles	-	-	-	9570	11115	7780	5220	-	-
<u>Avg. Size of Queues</u>[2]									
Direct Assistance	-	-	0	0	1	1	0	-	-
St. Lawrence Seaway Convoy	-	-	-	2/4	3/4	1/3	0/1	-	-

NOTES: 1. Second number is average percent time utilized.

2. First entry is upbound, second is downbound ; DA Queues indicate vessels which <u>are</u> waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are <u>not</u> waiting.

TABLE 6.28g

EXTENDED SEASON TONNAGE

BY ROUTE FOR RUN NO. 7

IRON ORE-LAKER

Route	Tons
1	647
2	1022
3	569
4	159
5	874
6	874
8	1403
9	1428
10	875
11	994
12	1706
13	1640
14	863
15	592
17	1155
19	872
20	473
21	283

IRON ORE-LAKER

Route	Tons
22	649
23	874
24	1022
26	603
27	437
28	606
29	1041
30	1440
32	542
33	870
34	612
35	490
37	1034
38	913
39	996
41	630
42	938
TOTAL	30126

COAL-LAKER

Route	Tons
44	1069
45	1088
46	1090
47	450
48	2861
49	1039
51	1186
53	181
54	978
56	121
57	100
58	226
59	224
60	594
61	1939
63	155
64	293
65	221
66	1357
68	201
69	201
70	434
71	607
72	2533
TOTAL	19148

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	640
78	1376
80	50
81	101
83	-
85	50
TOTAL	2217

GENERAL CARGO-SALTY

Route	Tons
87	453

BULK CARGO-SALTY

Route	Tons
88	6214
89	2638
90	703
91	332
92	444
93	602
TOTAL	10933
GRAND TOTAL	62877

Maximum Number of Vessels:

Lakers: 206
Salty General Cargo: 30
Salty Bulk: 130

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.29a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 8

Winter Type: Severe

Minimum Laker Class: 6

Run Mode: Maximum Response Time

USCG Estimated Fleet: N.A.

MRT (hr): Minimum + 12

Convoying Icebreaker Types: C,B

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000 (Class 5 Laker tonnage assumed carried in normal season)

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	6-10
St. Marys River/Whitefish Bay	50,51	-
Straits of Mackinac	53	7-10
Detroit/St. Clair River System	72,73	None
Welland Canal	89	6-7
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDSVL, SPDSVM, SPDSVH, SHIPNC5, EAGDMRT, RCH2SV6, RCH1S, CLASS

Archived Output File Name: PRO8A

TABLE 6.29b

PREDICTED ICEBREAKER FLEET BY HOME PORT AND PERIOD FOR RUN NO. 8

LOCATION	CLASS D									CLASS C									CLASS B								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
THUNDER BAY TC	-	-	-	1	-	-	-	-	-	-	-	-	-	4	-	3	-	-	-	-	-	-	-	5	-	-	-
Duluth	-	-	2	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	3	3	4	6	4
Presque Isle	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sault Ste. Marie	-	-	-	-	-	-	-	-	-	-	-	-	-	4	5	6	1	1	-	-	-	-	-	-	-	3	4
St. Ignace	-	-	-	-	2	-	-	-	-	-	-	-	-	-	2	2	2	2	-	-	-	-	-	-	-	-	-
TACONITE TC	-	-	2	-	2	-	-	-	-	-	-	-	9	4	7	8	3	3	-	-	-	-	3	3	4	9	8
Escanaba	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green Bay	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chicago	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL CAN TC	-	-	-	-	1	1	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Saginaw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Huron	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-
Detroit	-	-	-	-	-	-	2	-	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-	-	-	-
Toledo	-	-	-	-	18	-	1	-	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-	-	-	-
Sandusky	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cleveland	-	-	-	-	2	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo	-	-	1	-	-	-	8	-	-	-	-	-	-	-	25	-	3	-	-	-	-	4	4	5	2	-	-
COAL SHOVEL TC	-	-	1	-	22	-	11	-	-	-	-	-	-	-	47	-	3	-	-	-	-	4	4	5	2	-	-
Port Colborne	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	3	-	-	-	-	-	-	-	3	-	-	-
Toronto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WELLAND TC	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	3	-	-	-	-	-	-	-	3	-	-	-
Oswego	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alexandria Bay	-	-	-	-	-	-	2	-	-	-	-	-	4	8	-	-	1	-	-	-	-	-	-	5	3	-	-
SEAWAY TC	-	-	-	-	-	-	2	-	-	-	-	-	4	9	-	-	1	-	-	-	-	-	-	5	3	-	-
Montreal	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	5	5	4	2	-
Quebec	-	-	-	-	-	-	-	5	-	-	-	-	-	2	2	5	-	-	-	-	-	-	-	3	-	-	-
QUEBEC TC	-	-	-	-	-	-	-	5	-	-	-	-	7	2	2	5	-	-	-	-	-	-	5	8	4	2	-
U.S.	-	-	3	-	25	1	13	-	-	-	-	-	13	12	57	8	7	3	-	-	-	4	7	13	9	9	8

TABLE 6.29c

RESULTS OF RUN NO. 8

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	2-8%	-	2-17%	-	-	-	-
Class C	-	-	-	9-21%	4-71%	7-79%	8-68%	3-48%	3-55%
Class B	-	-	-	-	3-41%	3-39%	4-29%	9-37%	8-48%
TOTAL	-	-	2-8%	9-21%	9-49%	10-67%	12-55%	12-39%	11-50%
Direct Assists									
by Class D	-	-	9	-	11	-	-	-	-
by Class C	-	-	-	89	-	1	17	12	22
by Class B	-	-	-	-	104	93	94	104	115
TOTAL	-	-	9	89	115	94	111	116	137
Total Time (hr)	-	-	56	639	524	403	599	577	757
Total Miles	0	0	225	1861	2700	2071	2778	2923	4255
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	99	154	113	29	31
by Class B	-	-	-	-	-	-	-	78	83
TOTAL	-	-	-	-	99	154	113	107	114
Total Time (hr)	-	-	-	-	958	1833	1613	1009	1098
Total Miles	-	-	-	-	6026	9660	7580	6922	7898
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	0	0	1	1	2
St. Marys R. Convoy	-	-	-	-	18/4	18/2	12/1	12/0	15/1
Straits Convoy	-	-	-	-	-	4/4	3/3	2/1	4/3

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.29d

RESULTS OF RUN NO. 8

FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	1-24%	1-7%	-	-	-
Class C	-	-	-	-	-	3-15%	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	1-24%	4-13%	-	-	-
Direct Assists									
by Class D	-	-	-	-	3	2	-	-	-
by Class C	-	-	-	-	-	6	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	3	8	-	-	-
Total Time (hr)	-	-	-	-	82	169	-	-	-
Total Miles	-	-	-	-	320	792	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	-	0	0	-	-	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.29e

RESULTS OF RUN NO. 8

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	1-25%	-	22-20%	-	11-15%	-	-
Class C	-	-	-	-	-	47-27%	-	3-6%	-
Class B	-	-	-	4-11%	4-47%	5-29%	2-18%	-	-
TOTAL	-	-	1-25%	4-11%	26-24%	52-27%	13-16%	3-6%	-
Direct Assists									
by Class D	-	-	11	-	43	-	11	-	-
by Class C	-	-	-	-	-	138	-	18	-
by Class B	-	-	-	33	37	22	24	-	-
TOTAL	-	-	11	33	80	160	35	18	-
Total Time (hr)	-	-	83	152	2119	4752	701	64	-
Total Miles	-	-	172	926	11069	22080	3372	270	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	2	5	1	0	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.29f

RESULTS OF RUN NO. 8

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	2-4%	-	-
Class C	-	-	-	4-89%	8-91%	-	-	1-5%	-
Class B	-	-	-	-	-	5-76%	3-50%	-	-
TOTAL	-	-	-	4-89%	8-91%	5-76%	5-32%	1-5%	-
Direct Assists									
by Class D	-	-	-	-	-	-	2	-	-
by Class C	-	-	-	-	6	-	-	-	-
by Class B	-	-	-	-	-	15	-	-	-
TOTAL	-	-	-	-	6	15	2	-	-
Total Time (hr)	-	-	-	-	103	188	29	-	-
Total Miles	-	-	-	-	456	1236	120	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	44	51	-	-	1	-
by Class B	-	-	-	-	-	43	21	-	-
TOTAL	-	-	-	44	51	43	21	1	-
Total Time (hr)	-	-	-	1198	2340	1183	504	33	-
Total Miles	-	-	-	7975	10820	10535	4785	290	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	0	0	0	-	-
St. Lawrence Seaway Convoy	-	-	-	2/6	4/3	0/6	0/4	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound ; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.29g

EXTENDED SEASON TONNAGE
BY ROUTE FOR RUN NO.8

IRON ORE-LAKER

Route	Tons
1	489
2	794
3	435
4	-
5	672
6	673
8	1063
9	1077
10	673
11	766
12	1321
13	1251
14	675
15	450
17	861
19	662
20	368
21	144

IRON ORE-LAKER

Route	Tons
22	490
23	673
24	791
26	460
27	314
28	463
29	790
30	1102
32	399
33	676
34	471
35	364
37	782
38	701
39	765
41	486
42	700
TOTAL	22801

COAL-LAKER

Route	Tons
44	1070
45	1088
46	1088
47	450
48	2749
49	1038
51	1186
53	182
54	978
56	121
57	100
58	226
59	224
60	594
61	1864
63	155
64	291
65	221
66	1310
68	201
69	201
70	430
71	607
72	2424
TOTAL	18798

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	641
78	1029
80	50
81	100
83	-
85	50
TOTAL	1870

GENERAL CARGO-SALTY

Route	Tons
87	450

BULK CARGO-SALTY

Route	Tons
88	6224
89	2621
90	703
91	331
92	445
93	604
TOTAL	10928
GRAND TOTAL	54847

Maximum Number of Vessels:

Lakers: 142
Salty General Cargo: 29
Salty Bulk: 119

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.30a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 9

Winter Type: Severe

Minimum Laker Class: 6

Run Mode: Maximum Response Time

USCG Estimated Fleet: N.A.

MRT (hr): Minimum + 12

Convoying Icebreaker Types: C,B

Channel Clearing (in/per)*: 12

Cargo Tonnage (year): 2000 (Class 5 laker tonnage assumed carried in normal season)

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	6-10
St. Marys River/Whitefish Bay	50,51	-
Straits of Mackinac	53	7-10
Detroit/St. Clair River System	72,73	None
Welland Canal	89	6-7
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDSVLC, SPDSVMC, SPDSVHC, SHIPNC5, EAGDMRT, RC25V6C, RCH1S, CLASS

Archived Output File Name: PRO9A

* Channel clearing was in the following reaches: 50, 51, 53, 72, 73, 74, 76, 89, 95, 96 periods 2 through 10.

TABLE 6.30b

PREDICTED ICEBREAKER FLEET BY HOME PORT AND PERIOD FOR RUN NO. 9

LOCATION	CLASS D									CLASS C									CLASS B								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
THUNDER BAY TC	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	4	-	-	-
Duluth	-	-	3	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	2	3	2	3	2
Presque Isle	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sault Ste. Marie	-	-	-	-	-	-	-	-	-	-	-	-	-	3	4	3	3	2	-	-	-	-	-	-	-	-	-
St. Ignace	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	1	1	-	-	-	-	-	-	-	-	-
TACONITE TC	-	-	3	-	-	-	-	-	-	-	-	-	9	3	6	5	4	3	-	-	-	-	2	3	2	3	2
Escanaba	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green Bay	-	-	-	-	1	-	1	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chicago	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL CAN TC	-	-	-	-	1	1	1	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Saginaw	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Port Huron	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Detroit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toledo	-	-	-	-	20	-	2	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-
Sandusky	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cleveland	-	-	-	-	1	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo	-	-	2	-	-	-	7	-	-	-	-	-	-	-	25	-	2	-	-	-	-	4	4	6	3	-	-
COAL SHOVEL TC	-	-	2	-	23	-	9	-	-	-	-	-	-	-	47	-	2	-	-	-	-	4	4	6	3	-	-
Port Colborne	-	-	-	-	-	-	-	-	-	-	-	-	-	4	5	3	-	-	-	-	-	-	-	-	-	-	-
Toronto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WELLAND TC	-	-	-	-	-	-	-	-	-	-	-	-	-	4	5	3	-	-	-	-	-	-	-	-	-	-	-
Oswego	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alexandria Bay	-	-	-	-	-	-	-	-	-	-	-	-	4	5	1	3	1	-	-	-	-	-	-	3	-	-	-
SEAWAY TC	-	-	-	-	-	-	-	-	-	-	-	-	4	5	1	3	1	-	-	-	-	-	-	3	-	-	-
Montreal	-	-	-	-	-	-	-	-	-	-	-	-	5	4	4	4	-	-	-	-	-	-	-	-	-	-	-
Quebec	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	5	-	-	-	-	-	-	4	6	3	-	-
QUEBEC TC	-	-	-	-	-	-	-	5	-	-	-	-	5	4	4	9	-	-	-	-	-	-	4	6	3	-	-
U.S.	-	-	5	-	24	1	10	-	-	-	-	-	13	8	57	8	7	3	-	-	-	4	6	12	5	3	2

TABLE 6.30c

RESULTS OF RUN NO. 9

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	3-17%	-	-	-	-	-	-
Class C	-	-	-	9-23%	3-89%	6-62%	5-60%	4-73%	3-77%
Class B	-	-	-	-	2-64%	3-40%	2-59%	3-39%	2-57%
TOTAL	-	-	3-17%	9-23%	5-79%	9-55%	7-60%	7-59%	5-69%
Direct Assists									
by Class D	-	-	9	-	-	-	-	-	-
by Class C	-	-	-	96	-	-	-	-	-
by Class B	-	-	-	-	102	96	92	88	89
TOTAL	-	-	9	96	102	96	92	88	89
Total Time (hr)	-	-	56	682	430	401	393	397	383
Total Miles	-	-	225	1956	2760	2072	2147	2136	2204
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	111	168	133	126	115
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	111	168	133	126	115
Total Time (hr)	-	-	-	-	891	1252	1007	978	775
Total Miles	-	-	-	-	6946	10304	8694	8234	6578
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	0	0	2	0	0
St. Marys R. Convoy	-	-	-	-	19/1	15/1	10/0	11/0	12/2
Straits Convoy	-	-	-	-	-	4/4	2/3	1/1	3/2

NOTES: 1. Second number is average percent time utilized.

2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.30d

RESULTS OF RUN NO. 9

FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	1-19%	1-7%	1-10%	-	-
Class C	-	-	-	-	-	3-15%	-	-	-
Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	1-19%	4-13%	1-10%	-	-
Direct Assists									
by Class D	-	-	-	-	2	2	1	-	-
by Class C	-	-	-	-	-	6	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	2	8	1	-	-
Total Time (hr)	-	-	-	-	59	169	32	-	-
Total Miles	-	-	-	-	240	792	160	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	-	0	0	0	-	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.30e

RESULTS OF RUN NO. 9

FOR COAL SHOVEL TASK COMMAND

ITEM	2	3	4	5	6	7	8	9	10
					Period				
Number of Icebreakers[1]									
Class D	-	-	2-12%	-	23-20%	-	9-16%	-	-
Class C	-	-	-	-	-	47-22%	-	2-19%	
Class B	-	-	-	4-13%	4-43%	6-24%	3-12%	-	-
TOTAL	-	-	2-12%	4-13%	27-23%	53-22%	12-17%	2-19%	-
Direct Assists									
by Class D	-	-	11	-	44	-	10	-	-
by Class C	-	-	-	-	-	90	-	18	-
by Class B	-	-	-	36	34	24	25	-	-
TOTAL	-	-	11	36	78	114	35	18	-
Total Time (hr)	-	-	83	169	2092	3971	667	64	-
Total Miles	-	-	172	1036	10733	18073	3100	270	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	2	4	2	0	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.30f

RESULTS OF RUN NO. 9

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	-	-	-	4-85%	5-86%	1-98%	3-63%	1-5%	-
Class B	-	-	-	-	-	3-27%	-	-	-
TOTAL	-	-	-	4-85%	5-86%	4-86%	3-63%	1-5%	-
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	10	-	-	-	-
by Class B	-	-	-	-	-	9	-	-	-
TOTAL	-	-	-	-	10	9	-	-	-
Total Time (hr)	-	-	-	-	181	102	-	-	-
Total Miles	-	-	-	-	1056	636	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	52	57	11	25	1	-
by Class B	-	-	-	-	-	31	-	-	-
TOTAL	-	-	-	52	57	42	25	1	-
Total Time (hr)	-	-	-	1147	1256	1050	653	17	-
Total Miles	-	-	-	10730	11665	10040	6235	145	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	0	0	0	-	-	-
St. Lawrence Seaway Convoy	-	-	-	3/5	2/5	1/4	1/1	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound ; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.30g

EXTENDED SEASON TONNAGE

BY ROUTE FOR RUN NO. 9

IRON ORE-LAKER

Route	Tons
1	490
2	794
3	434
4	-
5	671
6	673
8	1069
9	1111
10	673
11	765
12	1320
13	1248
14	673
15	461
17	890
19	672
20	369
21	144

IRON ORE-LAKER

Route	Tons
22	489
23	673
24	792
26	458
27	315
28	462
29	789
30	1109
32	413
33	673
34	472
35	369
37	782
38	703
39	766
41	483
42	697
TOTAL	22902

COAL-LAKER

Route	Tons
44	1080
45	1090
46	1090
47	448
48	2763
49	1038
51	1186
53	181
54	978
56	121
57	100
58	226
59	224
60	594
61	1864
63	155
64	293
65	221
66	1310
68	201
69	201
70	428
71	607
72	2424
TOTAL	18823

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	651
78	1036
80	50
81	99
83	-
85	50
TOTAL	1886

GENERAL CARGO-SALTY

Route	Tons
87	443

BULK CARGO-SALTY

Route	Tons
88	6250
89	2641
90	710
91	330
92	444
93	603
TOTAL	10978
GRAND TOTAL	55032

Maximum Number of Vessels:

Lakers: 130
Salty General Cargo: 28
Salty Bulk: 114

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

TABLE 6.31a

SUMMARY OF INPUT CONDITIONS
FOR RUN NO. 10

Winter Type: Severe

Minimum Laker Class: 6

Run Mode: Fixed Icebreaker Fleet

USCG Estimated Fleet: Severe

MRT (hr): N.A.

Convoying Icebreaker Types: C,B

Channel Clearing (in/per): None

Cargo Tonnage (year): 2000 (Class 5 laker tonnage assumed carried in normal season)

Convoy Routes:

Location	Reaches	Periods
St. Marys River	51	6-10
St. Marys River/Whitefish Bay	50,51	-
Straits of Mackinac	53	7-10
Detroit/St. Clair River System	72,73	None
Welland Canal	89	6-7
U.S. St. Lawrence Seaway	95	5-8
Canadian St. Lawrence Seaway	96	5-8

Data Files Used: SPDSVL, SPDSVM, SPDSVH, SHSVNC5, EAGDFIB, RCH2SV6, RCH1S, CLASS

Archived Output File Name: PR010

TABLE 6.31b

USCG ESTIMATED FLEET* FOR SEVERE WINTER
FOR RUN NO. 10

Home Port	Class B	Class C	Class D
Duluth	1	2	-
Sault Ste. Marie	3	6	-
St. Ignace	3	6	-
Port Huron, Detroit, Toledo	1	4	-
Escanaba	-	1	-
Chicago	1	2	-
Saginaw	2	3	-
Sandusky	1	2	-
Buffalo	1	4	-
Oswego	-	3	-
SUBTOTAL	12	29	2
TOTAL		43	

NOTE: Principal ports; operations limited to vessels of reasonably high capability (SHP/L > 6); 12 hrs per day per icebreaker.

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* Letter dated 8 June 1977 from Commander, Ninth Coast Guard District to the Commandant (G-O).

TABLE 6.31c

RESULTS OF RUN NO. 10

FOR TACONITE TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	2-0%	2-0%	2-0%	2-0%	2-15%	2-0%	2-68%	2-8%	2-0%
Class C	10-0%	10-0%	10-1%	10-9%	10-55%	10-64%	10-73%	10-56%	10-99%
Class B	6-0%	6-0%	6-0%	6-29%	6-102%	6-98%	6-103%	6-96%	6-10%
TOTAL	18-0%	18-0%	18-1%	18-15%	18-66%	18-6%	18-82%	18-64%	18-88%
Direct Assists									
by Class D	-	-	-	-	10	-	10	-	-
by Class C	-	-	7	41	-	-	5	14	56
by Class B	-	-	2	48	101	89	89	83	104
TOTAL	-	-	9	89	111	89	104	99	160
Total Time (hr)	-	-	40	894	1350	1007	1691	1378	2360
Total Miles	-	-	225	9096	16168	11547	16115	14096	18581
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	129	126	114	37	41
by Class B	-	-	-	-	27	29	26	42	50
TOTAL	-	-	-	-	156	155	140	79	91
Total Time (hr)	-	-	-	-	2641	3089	3284	2488	2976
Total Miles	-	-	-	-	26713	27742	28046	19018	20204
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	1	3	2	3	5
St. Marys R. Convoy	-	-	-	-	11/0	12/0	9/0	16/3	19/3
Straits Convoy	-	-	-	-	-	2/2	2/2	3/2	1/1

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues indicate vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.31d

RESULTS OF RUN NO. 10

FOR OIL CAN TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	3-0%	3-0%	3-0%	3-0%	3-8%	3-24%	3-0%	3-0%	3-0%
Class B	1-0%	1-0%	1-0%	1-0%	1-0%	1-12%	1-0%	1-0%	1-0%
TOTAL	4-0%	4-0%	4-0%	4-0%	4-6%	4-21%	4-0%	4-0%	4-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	3	7	-	-	-
by Class B	-	-	-	-	-	1	-	-	-
TOTAL	-	-	-	-	3	8	-	-	-
Total Time (hr)	-	-	-	-	85	284	-	-	-
Total Miles	-	-	-	-	544	2698	-	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues									
Direct Assistance	-	-	-	-	0	0	-	-	-

NOTE: 1. Second number is average percent time utilized.

TABLE 6.31e

RESULTS OF RUN NO. 10

FOR COAL SHOVEL TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	12-	12-	12-1%	12-0%	12-23%	12-84%	12-6%	12-0%	12-0%
Class B	5-	5-	5-0%	5-16%	5-82%	5-91%	5-25%	5-1%	5-0%
TOTAL	17-	17-	17-1%	17-5%	17-40%	17-86%	17-12%	17-0%	17-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	6	-	31	101	3	-	-
by Class B	-	-	5	33	50	62	25	-	-
TOTAL	-	-	11	33	81	163	28	-	-
Total Time (hr)	-	-	39	272	2300	4914	671	-	-
Total Miles	-	-	132	2696	19080	34174	6888	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	-	-	-	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-
Total Time (hr)	-	-	-	-	-	-	-	-	-
Total Miles	-	-	-	-	-	-	-	-	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	0	0	0	0	0	-	-
Detroit/St. Clair Convoy	-	-	-	-	-	-	-	-	-

NOTES: 1. Second number is average percent time utilized.
2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.31f

RESULTS OF RUN NO. 10

FOR SEAWAY TASK COMMAND

ITEM	Period 2	3	4	5	6	7	8	9	10
Number of Icebreakers[1]									
Class D	-	-	-	-	-	-	-	-	-
Class C	3-0%	3-0%	3-0%	3-108%	3-99%	3-112%	3-99%	3-33%	3-0%
Class B	-	-	-	-	-	-	-	-	-
TOTAL	3-0%	3-0%	3-0%	3-108%	3-99%	3-112%	3-99%	3-33%	3-0%
Direct Assists									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	-	3	4	7	-	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	3	4	7	-	-
Total Time (hr)	-	-	-	-	77	117	125	-	-
Total Miles	-	-	-	-	360	312	600	-	-
Convoys Escorted									
by Class D	-	-	-	-	-	-	-	-	-
by Class C	-	-	-	43	27	21	22	18	-
by Class B	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	43	27	21	22	18	-
Total Time (hr)	-	-	-	1089	919	1012	830	331	-
Total Miles	-	-	-	7227	3975	3135	3310	3022	-
Avg. Size of Queues[2]									
Direct Assistance	-	-	-	-	1	4	4	-	-
St. Lawrence Seaway Convoy	-	-	-	5/8	20/13	51/24	45/26	8/6	-

NOTES: 1. Second number is average percent time utilized; values greater than 100% sometimes result because time for assists and convoys not completed during previous period are included.

2. First entry is upbound, second is downbound; DA Queues indicate vessels which are waiting, while Convoy Queues denote vessels which have established an ETA at convoy points and in general are not waiting.

TABLE 6.31g

EXTENDED SEASON TONNAGE
BY ROUTE FOR RUN NO. 10

IRON ORE-LAKER

Route	Tons
1	489
2	794
3	434
4	-
5	672
6	673
8	1045
9	1077
10	675
11	765
12	1320
13	1253
14	670
15	449
17	860
19	616
20	369
21	144

IRON ORE-LAKER

Route	Tons
22	490
23	673
24	792
26	460
27	313
28	463
29	783
30	1063
32	399
33	664
34	464
35	364
37	782
38	701
39	765
41	484
42	698
TOTAL	22663

COAL-LAKER

Route	Tons
44	1068
45	1072
46	1073
47	450
48	2691
49	1040
51	1176
53	182
54	978
56	121
57	100
58	226
59	224
60	595
61	1812
63	155
64	291
65	221
66	1310
68	201
69	201
70	435
71	606
72	2424
TOTAL	18652

GRAIN-LAKER

Route	Tons
74	-
75	-
76	-
77	626
78	1016
80	50
81	100
83	-
85	50
TOTAL	1842

GENERAL CARGO-SALTY

Route	Tons
87	473

BULK CARGO-SALTY

Route	Tons
88	6083
89	2615
90	703
91	332
92	446
93	609
TOTAL	10788

GRAND TOTAL 54418

Maximum Number of Vessels:

Lakers: 140
Salty General Cargo: 29
Salty Bulk: 123

NOTES: 1. Units are thousands of short tons.
2. Extended season consists of nine 14-day periods.

7. CONCLUSIONS

Based on the results and discussion of the ten (10) production runs presented in Section 7, the following conclusions were drawn:

1. Usefulness of the Simulation - Based on the validation presented in Section 6.2 and the experience and knowledge we have gained from working with the model, from conversations with ship operators, port officials, and personnel at Coast Guard, MarAd, Corps of Engineers, and the St. Lawrence Seaway Development Corporation, we believe the simulation, as developed, realistically models the Great Lakes-St. Lawrence Seaway System. As a result, it can be used as a valuable tool to aid in the planning process of the Coast Guard in establishing their future icebreaking requirements and alternate icebreaking plans and concepts of operation.

2. Normal and Severe Winter Icebreaker Fleets - Using the results of the simulation for the fixed icebreaker fleet runs and the generated icebreaker fleet runs, simulation estimated icebreaker fleets were prepared and are presented in Tables 7.1 and 7.2 along with the Coast Guard estimated fleet for normal and severe winters. In finalizing the simulation fleet, consideration was given to additional icebreaking demands, such as preventive icebreaking and channel maintenance. In comparing the results of the simulation to those of the Coast Guard it is interesting to note how closely they compared in number with some shifting in location.

   The procedure used for development of the "simulation generated icebreaker fleet" was a subjective process in which we tried to weigh the results of the 10 simulation runs to come up with a fleet we could recommend to the Coast Guard as a starting point for further sensitivity studies of the icebreaker requirements as discussed in the recommendations. Specifically the rationale we used to generate the fleets tested in Tables 7.1 and 7.2 were as follows:

   TACONITE: For the severe winter, based on the results of runs 8 and 10 and noting the time spent by icebreakers transiting Lake Superior, it was concluded that 2 Class B and 2 Class C icebreakers in Duluth/Superior, 2 Class B and 6 Class C icebreakers in Sault Ste. Marie and 1 Class B and 3 Class C icebreakers in St. Ignace could handle the projected traffic. Similarly for the normal winter based on the results of runs 1 and 3 and the time spent by icebreakers transiting Lake Superior, it was concluded that

TABLE 7.1

COMPARISON OF SIMULATION GENERATED
ICEBREAKER FLEET WITH COAST GUARD ESTIMATED FLEET
FOR NORMAL WINTER

Task Command & Home Port	U.S. COAST GUARD ESTIMATED ICEBREAKER FLEET (Icebreaker Class)				SIMULATION GENERATED ICEBREAKER FLEET (Icebreaker Class)			
	B	C	D	TOTAL	B	C	D	TOTAL
Taconite Command								
Duluth/Superior	-	2	-	2	2	-	-	2
Presque Isle	-	-	-	-	-	-	-	-
Sault Ste. Marie	2	4	-	6	1	5	-	6
St. Ignace	1	1	-	2	-	2	-	2
TOTAL	3	7	-	10	3	7	-	10
Oil Can Command								
Escanaba	-	1	-	1	-	2	-	2
Green Bay	-	-	-	-	-	-	-	-
Milwaukee	-	-	-	-	-	-	-	-
Chicago	-	1	-	1	-	-	-	-
Grand Haven	-	-	-	-	-	-	-	-
TOTAL	-	2	-	2	-	2	-	2
Coal Shovel Command								
Saginaw	-	-	-	-	-	-	-	-
Port Huron/Detroit/ Toledo	1	2	-	3	-	5	-	5
Sandusky	-	1	-	1	-	-	-	-
Buffalo	1	2	-	3	1	2	-	3
TOTAL	2	5	-	7	1	7	-	8
Seaway Command								
Oswego	-	3	-	3	-	-	-	-
Alexandria Bay	-	-	-	-	-	4	-	4
TOTAL	-	3	-	3	-	4	-	4
TOTAL	5	17	-	22	4	20	-	24

TABLE 7.2

COMPARISON OF SIMULATION GENERATED
ICEBREAKER FLEET WITH COAST GUARD ESTIMATED FLEET
FOR SEVERE WINTER

Task Command & Home Port	U.S. COAST GUARD ESTIMATED ICEBREAKER FLEET — Icebreaker Class B	C	D	TOTAL	SIMULATION GENERATED ICEBREAKER FLEET — Icebreaker Class B	C	D	TOTAL
Taconite Command								
Duluth/Superior	1	2	-	3	2	2	-	4
Presque Isle	-	-	-	-	-	-	-	-
Sault Ste. Marie	3	6	-	9	2	6	-	8
St. Ignace	2	2	2	6	1	3	-	4
TOTAL	6	10	2	18	5	11	-	16
Oil Can Command								
Escanaba	-	1	-	1	1	-	1	2
Green Bay	-	-	-	-	-	1	-	1
Milwaukee	-	-	-	-	-	-	-	-
Chicago	1	2	-	3	-	1	-	1
Grand Haven	-	-	-	-	-	-	-	-
TOTAL	1	3	-	4	1	2	1	4
Coal Shovel Command								
Saginaw	2	3	-	5	-	-	-	-
Port Huron/Detroit/ Toledo	1	4	-	5	1	5	2	8
Sandusky	1	2	-	3	-	2	-	2
Buffalo	1	4	-	5	3	5	-	8
TOTAL	5	13	-	18	4	12	2	18
Seaway Command								
Oswego	-	3	-	3	-	-	-	-
Alexandria Bay	-	-	-	-	1	3	-	4
TOTAL	-	3	-	3	1	3	-	4
TOTAL	12	29	2	43	11	28	3	42

- 2 Class B icebreakers in Duluth/Superior, 1 Class B and 5 Class C icebreakers in Sault Ste. Marie, and 2 Class C icebreakers in St. Ignace could handle the projected traffic. In generating both of these fleets, it was assumed that icebreakers would be prohibited from traversing Lake Superior between Duluth/Superior and the Soo.

  OIL CAN: For the severe winter, based on the results of runs 8 and 10, and, in particular, the magnitude of the icebreaker utilization, it was concluded that 1 Class B and 1 Class D icebreaker in Escanaba, 1 Class C icebreaker in Green Bay and 1 Class C icebreaker in Chicago could handle the projected traffic. In a similar manner, for the normal winter based on the results of runs 1 and 3 it was concluded that 2 Class C icebreakers in Escanaba could handle the projected traffic.

  COAL SHOVEL: For the severe winter based on results of runs 8 and 10 and looking particularly at icebreaker utilization and the locations where assistance was needed within the command, it was concluded that 1 Class B, 5 Class C and 2 Class D icebreakers in the Detroit area, 2 Class C icebreakers in Sandusky and, 3 Class B and 5 Class C in Buffalo could handle the projected traffic. In a similar manner for the normal winter, it was concluded that 5 Class C icebreakers in the Detroit area and 1 Class B and 2 Class C icebreakers in Buffalo could handle the projected traffic.

  SEAWAY: Based on the results of runs 8 and 10 for the severe winter and runs 1 and 3 for the normal winter, and looking particularly at icebreaker utilization, the location of direct assists and the number of conovys escorted, it was concluded that 1 Class B and 3 Class C icebreakers could handle the projected traffic in a severe winter and the 4 Class C icebreakers could handle the projected traffic in a normal winter.

3. Formation of New Task Command for Duluth/Superior - Icebreakers in the simulation for the fixed fleet mode continually traveled across Lake Superior to provide assistance in both Duluth/Superior and at the Soo since assistance was provided on a first come-first serve basis. As a result, a large amount of time was spent transiting Lake Superior compared to time spent either assisting or convoying. For example, in Run 1 for the normal winter, the fixed fleet of 7 Class C and 3 Class B icebreakers operated at 100% utilization performing 781 direct assists and escorting 629 convoys. Of the 100% utilization in periods 5, 6, and 7, only 10%, 20%, and 29% of the total direct assist miles and 20%, 58% and 44% of the total convoy miles were spent in actual assistance and convoying

for each period, respectively. In comparison, the somewhat larger MRT generated fleet, which was restricted to operating within assigned areas near the icebreaker's home port, averaged 61%, 74%, and 75% of total direct assistance miles and 74%, 70%, and 66% of total convoy miles performing actual direct assistance and convoying in periods 5, 6, and 7, respectively. Future runs should have a 200 mile limitation placed on the icebreaker's area of operation to prohibit transiting Lake Superior, thereby effectively making Duluth/Superior a separate task command.

4. Effect of Increased Tonnage - For the fixed normal winter icebreaker fleet, the designated icebreakers in Oil Can and Coal Shovel could handle the 20% increased tonnage above the projected year 2000 tonnage with no significant problems. For the Seaway, the 3 Class C icebreakers operated 100% utilization in periods 5 through 8 escorting 173 convoys between Alexandria Bay and Cornwall. Based on the MRT runs 2 and 3, 5 or 6 Class C icebreakers or 1 Class B plus 3 Class C icebreakers were probably required to escort all vessels in convoys at a reasonable icebreaker utilization rate. In Taconite, the fixed fleet operated at 100% utilization because a large portion of the time was spent by icebreakers transiting between Duluth/Superior and the Soo. Based on the MRT runs 2 and 3, in which icebreakers were restricted to operating within assigned areas near the icebreaker's home port, the specified fixed fleet of 7 Class C and 3 Class B icebreakers needs to be increased to 9 Class C and 4 Class B icebreakers with Duluth/Superior being treated as a separate task command.

5. Effect of Increased Maximum Response Time - For Taconite, Oil Can and Coal Shovel Task Commands, there appeared to be only a slight effect on the generated icebreaker fleet due to increasing the MRT by 12 hours. For the Seaway, the maximum number of required Class C icebreakers dropped from 6 to 5.

6. Effect of Convoying - For Oil Can and Coal Shovel, where there were no convoys, the effect of convoying was a change in the arrival of ships from other commands which altered the generated icebreaker fleet slightly. For the Seaway, the elimination of convoying reduced the icebreaker requirements significantly since salties, which were capable of proceeding on their own, were being forced to convoy, thereby requiring more icebreakers. In Taconite, elimination of convoying caused the generated icebreaker fleet to double in periods 5 through 10.

7. Effect of Winter Severity - As one would expect, the icebreaking requirements increased with increasing winter

severity. In Taconite, the total number of direct assists increased from 792 to 1032 and the total number of convoys increased from 699 to 937, resulting in an increase of required icebreakers from an average of 11 to 20, with an increase in Class B icebreakers from an average of 4 to approximately 6. In Oil Can, the total number of direct assists increased from 86 to 102, but because the location of the problem reach was closer to the icebreaker home port of Escanaba, fewer icebreakers were required during the severe year. The reason for this seemingly contradictory trend is a result of the use of actual historical weather and ice data which is sometimes inconsistent. In Coal Shovel, the number of direct assists increased by almost 200% from 198 to 573 with 347 convoys being escorted during the severe winter. This resulted in the number of icebreakers being doubled with an average of 4 Class B icebreakers being required during the severe winter while none were required during the normal winter. For the Seaway, the total number of direct assists increased from zero in the normal winter to 40 in the severe winter, but the total number of convoys decreased from 185 to 154. This reduction was due to Class B icebreakers being generated instead of Class C icebreakers (Class B icebreakers can handle twice as many ships per convoy as can Class C icebreakers). For the normal winter, between 3 and 5 Class C icebreakers were required while for the severe winter the icebreaker fleet ranged from 1 Class D and 4 Class C icebreakers to 4 Class B icebreakers.

8. Effect of Prohibiting Class C Icebreakers from Convoying - For Oil Can and Coal Shovel, restricting Class C icebreakers from convoying did not significantly reduce the number of icebreakers generated. For Coal Shovel, however, it did tend to replace each Class C icebreaker eliminated with an equal number of Class B icebreakers, indicating that the increased convoying capability of Class B icebreakers was not utilized. For the Seaway, the maximum generated icebreaker fleet changed from 11 Class C icebreakers to 1 Class C and 4 Class B icebreakers for period 6. At Taconite, for all periods, the average total number of icebreakers required decreased by 21%, with Class C icebreakers almost completely eliminated and 1 additional Class B icebreaker added for every 2 Class C icebreakers eliminated.

9. Effect of Increased SHP/Length Restriction - The removal of Class 5 laker vessels (SHP/lengths = 6.25) from the fleet reduced the icebreaking requirements significantly in all task commands. In Taconite, the number of direct assists dropped from 1032 to 671 and the number of convoys escorted dropped from 937 to 587. This resulted in a reduction in the generated icebreaker fleet by more than 50%. In Oil Can the number of direct assists decreased from 102 to 11,

resulting in a reduction in the number of icebreakers from an average of 5 icebreakers in periods 3 through 7 to an average of one icebreaker in periods 6 and 7. In Coal Shovel, with the exception of period 7, the number of required icebreakers decreased by a factor of 2 due to the total number of direct assists dropping from 573 to 337 and the elimination of 347 convoys. In the Seaway, the total number of direct assists decreased from 40 to 20 and the total number of convoys decreased slightly from 160 to 154, resulting in a reduction in icebreaking requirements by approximately one third.

10. Effect of Channel Clearing - The primary effect of channel clearing which, in run 9, was performed in reaches where convoying occurred, was to: (1) decrease the size of icebreakers required for convoying, and (2) increase icebreaker speeds which allowed each icebreaker to effectively handle more convoys, at times comprised of fewer ships due to ship arrival frequency. For Oil Can and Coal Shovel where there was no convoying, almost no effect from channel clearing was observed. In the Seaway, both the size and number of icebreakers were reduced. For example, in period 6, 8 Class C icebreakers were replaced by 5 Class C icebreakers with channel clearing. In period 7, 5 Class B icebreakers were replaced with 3 Class B icebreakers and 1 Class C. For Taconite, a similar condition occurred in that both the number and size of icebreakers were reduced. In period 8, the required 12 icebreakers (8 Class C and 4 Class B) were replaced by 7 icebreakers (5 Class C and 2 Class B).

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COMPUTER SIMULATION OF GREAT LAKES-ST. LAWRENCE SEAWAY ICEBREAK--ETC(U)
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UNCLASSIFIED 296C-4 USCG-D-56-79 NL

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8. RECOMMENDATIONS

Based on the conclusions and general discussions included in this report, as well as the knowledge we have gained during the course of this study, we recommend the following:

1. The GL-SLS NAVIGATION SIMULATION should be kept current by revising the input data files and changing the basic rules and assumptions as required. We believe this simulation is an excellent planning tool which can be used as an aid to the U.S. Coast Guard in establishing their future icebreaking requirements and evaluating alternate icebreaker plans and concepts of operation, such as direct assistance, convoying, channel maintenance and channel ice clearing, as to their impact on extended commercial navigation operations and economics. In addition, the simulation can be used by the Corps of Engineers as a planning tool to aid in their assessment of the potential benefits and impacts of various proposed GL-SLS System improvements for normal navigation season operations as well as extended navigation season operations.

2. We also recommend that, as additional extended navigation season operations continue and more icebreaker operational data is gathered, additional validation runs be performed to ensure the continued credibility of the simulation.

3. To gain further insight and a more comprehensive understanding of the impacts on icebreaker requirements and commercial navigation operations and economics, we recommend that additional sensitivity runs be performed on:

   - Variations of fixed icebreaker fleets and home ports
   - Variations in channel clearing and preventive icebreaking
   - Variations in MRT mode conditions
   - Variations in ice conditions
   - Variations in low SHP/length restriction

4. During the course of modifying the simulation and conducting the runs, we found that the following revisions to the simulation should be considered.

- Revise Fixed Fleet Mode to prohibit icebreakers from traveling over long distances within a task command, such as an icebreaker continually traversing Lake Superior between Duluth/Superior and the Soo.
- Incorporate a probability basis for ships getting or not getting stuck rather than the current assumption of all ships of a given class getting stuck if their speed of advance is less than 2 mph; that is, apply a probability distribution which would vary linearly with the speed of advance between a probability of getting stuck equal to 1 at some designated speed, and a probability equal to 0.0 at some higher designated speed. In this manner, the "off-on" switch for all ships in a given class either being or not being stuck would be eliminated.
- For ease of data analysis, revise the REPORT GENERATING MODEL to provide summary tables similar to those listed in Section 6.4 for each run.

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